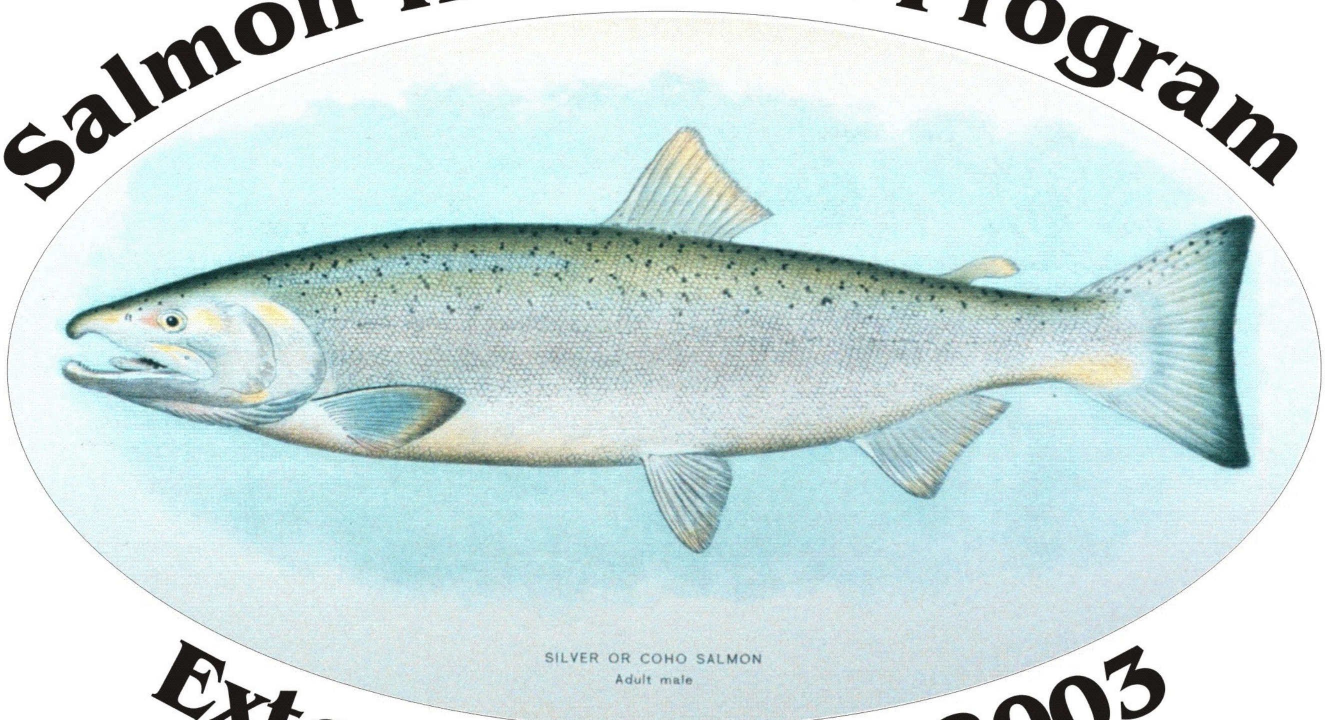
National Marine Fisheries Service
Southwest Fisheries Science Center

Salmon Research Program



External Review 2003

Santa Cruz, California
September 16-17, 2003

National Marine Fisheries Service
Southwest Fisheries Science Center

SALMON RESEARCH PROGRAM
EXTERNAL REVIEW 2003

September 16-17, 2003

U. S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center
Santa Cruz Laboratory
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Cover image:

Silver or coho salmon, adult male. Color drawing by A. H. Baldwin. Plate XXXI in: B. W. Evermann and E. L. Goldsborough, The fishes of Alaska. U. S. Department of Commerce and Labor, Bulletin of the Bureau of Fisheries. Document No. 624. U. S. Government Printing Office, 1907.

AGENDA

Monday, September 15

Review Panel arrives and organizational dinner

Tuesday, September 16

Welcome, Introductions and Housekeeping	Grimes	0800-0830
Introduction to the Santa Cruz and Pacific Fisheries Environmental Laboratories and Salmon Research Program		
Salmon Population Analysis		
Team Overview	Adams	0830-0900
Recovery Science - Coastal California	Bjorkstedt	0900-0930
Recovery Science - Central Valley	Lindley	0930-1000
BREAK		1000-1015
Coastal Monitoring Plan	Boughton	1015-1045
Ocean Harvest Management	Mohr	1045-1115
Economic Analysis	Thomson/Tomberlin	1115-1200
LUNCH		1200-1300
Early Life History		
Juvenile Steelhead Ecology	Sogard	1300-1315
Ocean Ecology		
Ocean Habitat Utilization and Population Dynamics	Watters	1315-1415
Ocean and San Francisco Estuary Physiological Ecology	MacFarlane	1415-1500
Physiological Ecology in Small Estuaries	Freund	1500-1515
BREAK		1515-1530
Molecular Ecology		
Comparative Wild and Hatchery Studies	Hayes	1530-1600
Population Structure	Garza	1600-1630
Deliberation and Organization of Review	Panel	1630-1700
ADJOURN		

Wednesday, September 17

Tour of Facilities	0900-0930
Interviews and Discussion with Laboratory Staff, Deliberation and Formulation of Report	0930-1200
LUNCH	1000-1330
Drafting of Report	1330-1500
Discussion with Senior Staff	1500-1530
Oral Report with Panel Conclusions and Recommendations	1530-1600
Completion of Report	1600-1700
ADJOURN	

PROSPECTUS
for
The Review of the Salmon Research Program of the Southwest Fisheries Science Center

September 16-17, 2003

The salmon research program of the National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), Southwest Fisheries Science Center (SWFSC), Santa Cruz Laboratory will be reviewed by an external panel of experts September 16-17, 2003, in Santa Cruz, California. The overarching goal of the research program is to conduct research relevant to providing scientific advice on the restoration and recovery of ESA listed salmonid species in California.

The Review Process

The Review Panel will be familiarized with the current and planned goals, objectives, approaches, activities and accomplishments of the salmonid research program via written summaries included in this document, and through a series of oral presentations on Tuesday, September 16. Questions and discussions during and/or following presentations should further the Panel's understanding of the research program, as will visits and discussions with individuals or groups of investigators planned for Wednesday, September 17.

On Monday evening or Tuesday morning, the Panel should organize (select a Chair, etc.) however it sees fit to accomplish the review.

On Tuesday afternoon, some time is scheduled for the Panel to begin deliberation, to discuss findings and formulate recommendations and conclusions. On Wednesday afternoon, additional time will be allocated for completing deliberations and preparation of the written Panel report. An oral summary of the Panel findings, including the main conclusions and recommendations, will be separately presented to the SWFSC senior management and the entire SWFSC salmon research staff on Wednesday afternoon. The format for the Panel report is unspecified, but we recommend it be organized according to the research programs, and can include comments, assessments, conclusions, etc., on virtually all aspects of the salmon scientific enterprise of the SWFSC, but at least should address the issues and questions laid out below.

The review Panel is charged with reviewing and commenting on the quality, effectiveness, efficiency, direction, focus, scope, organization, etc., of the research program, and making recommendation for improvements. The information contained in this document and/or presented orally during the Review will allow the Panel to carry out this charge:

- An organizational chart.

- A short written overview and oral presentation of the research goals, as well as NOAA, NMFS, SWFSC mission, organization and goals.

- Written reports and oral presentations on current and planned research activities and results.

- Curricula vitae of staff.

- A list of publications of the staff (1998-2003).
- Discussions/interviews with Laboratory staff by the Panel during oral presentations and/or individually.

In reviewing the program, the Panel should consider, but not be limited to, the following questions:

- Given the young age of the SWFSC salmon program and its stated goals and objectives, are planned and current activities appropriate to meet these goals and objectives effectively and efficiently?
- Are the research goals and objectives appropriate to meet the overarching restoration and recovery mission of NOAA, NMFS and SWFSC?
- Are there research and funding opportunities that should be incorporated into the research program?
- Are the best or optimum methods, techniques and technologies being used in the conduct of salmonid research?
- Do the scientific contributions of the program have high quality, advance resources science and provide leadership in research and sound advice to managers?
- Is the organizational structure of the SWFSC salmon program appropriate to meet national and regional salmonid research needs?

Where the Review Will Take Place

The review will take place at the National Marine Fisheries Service's Santa Cruz Laboratory, 110 Shaffer Road, Santa Cruz, California 95060. Telephone: (831) 420-3931.

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OVERVIEW OF THE SOUTHWEST FISHERY SCIENCE CENTER SALMON RESEARCH PROGRAM

Organization

The National Marine Fisheries Service (NMFS) is a division of the National Oceanic and Atmospheric Administration (NOAA), which resides in the United States Department of Commerce. NMFS can be referred to as NOAA Fisheries. The field operations of NMFS fall within 5 geographic regions. The southwestern U.S. falls within the jurisdiction of the Southwest Region (SWR),headquartered in Long Beach, California and the Southwest Fishery Science Center (SWFSC) headquartered in La Jolla, California.

The Santa Cruz Laboratory (SCL) is one of three laboratories comprising the SWFSC. In addition to La Jolla and Santa Cruz, the other laboratory (Pacific Fisheries Environmental Laboratory-PFEL) is located in Pacific Grove, California. The SWFSC salmon research program is principally located at SCL, but projects more closely related to oceanographic research are also conducted at PFEL. The Director of SCL, Dr. Churchill B. Grimes, and PFEL, Dr. Michael Laurs, report to Dr. Michael Tillman, Science Director of the SWFSC, through his deputy Dr. Richard A. Neal.

The Santa Cruz Laboratory salmon research programs are divided into two branches: Fisheries and Ecology. The Fisheries Branch's main function is to investigate West Coast salmonid population and conversation biology and to apply the information gained in this research to NMFS Endangered Species Act (ESA) activities and salmon harvest management. The Branch is made up of two teams, Salmon Population Analysis and Economics, and is lead by Dr. Peter B. Adams. The Salmon Population Analysis Team conducts field research, modeling studies, development of quantitative methods, and economic analysis connected with Pacific salmonids. Due to the paucity of data, field studies have focused on simple distributional studies of salmonids, along with more ongoing studies investigating life-stage specific population rates and the relationship between anadromous and non-anadromous steelhead. The modeling studies focus on population viability analysis, metapopulation modeling, spatial analysis using Geographical Information Systems (GIS), and salmon harvest modeling. Also because of the paucity of data, the Team has spent considerable time in the development of statistical estimators, including out-migrant trapping and multi-stage juvenile abundance estimation. The Economics Team is investigating economics of habitat-restoration efforts, an area where there has been no research to date, as well as economic analysis of harvest management and other regulatory activities. Branch scientists provide the core of SWFSC's scientific advice to salmonid management activities, and as a consequence spend a considerable amount of their time participating in ESA and harvest management activities.

The Ecology Branch conducts research to increase understanding of the relationships between fishes and their environments. The Branch is made up of three teams; Early Life History, Salmon Ecology, and Molecular Ecology, and is lead by Dr. Susan Sogard. The Early Life History Team investigates the role of environmental factors on growth and survival for age-0 steelhead and the role of larval quality and growth rates on survival and plasticity in life history trajectories. The Salmon Ecology Team focuses on basic ecology and physiology of salmonids and the influences of estuarine and marine habitats on their condition. The Team is investigating salmonid use of large and small estuaries, comparative studies of wild and hatchery coho and steelhead, and operates the southern coho captive broodstock program. The Molecular Ecology Team uses molecular and population genetic methods to study salmonid biological systems in California. Due to the paucity of basic genetic studies in California, baseline population structure studies of steelhead, coho, and chinook are the first genetic studies being conducted. The Team works closely with several hatchery programs both to investigate the genetic impact of hatcheries on California salmonids, and to lend guidance to improve California hatchery programs. Ecology Branch scientists also support salmonid management in California.

PFEL salmon research is focused on understanding how environmental variability influences fish production and how to improve scientific advice to deal with this variability. The salmon research is centered on three separate areas; habitat-utilization studies, correlative modeling, and population-dynamics modeling. The habitat-utilization studies use archival tags to identify the marine habitat of chinook salmon and then to characterize that habitat oceanographically across years and seasons. Correlative statistical modeling of fish populations with ocean conditions is an ongoing focus of research at PFEL, and is being used to investigate the relationship between ocean conditions and key salmonid population parameters such as age-at-maturity and survival at first entry to the ocean. The population-dynamics modeling synthesizes multiple types of data to evaluate the influence of environmental variation on salmon production, and this work is interactive with the correlative modeling.

Santa Cruz Laboratory

Partnerships

Cooperative relationships with other organizations assist the laboratory in accomplishing the research mission. The principal academic partner of the laboratory is the University of California at Santa Cruz (UCSC) with whom laboratory scientists conduct collaborative research, and participate in graduate academic programs through courtesy faculty appointments. Collaborative research topics cut across the full breadth of the salmon research program. The Center for Stock Assessment Research (CSTAR) is a prominent feature of the partnership with UCSC. Other research partners include United States Geological Survey, the University of California at Santa Barbara, Moss Landing Marine Laboratories, Humboldt State University, California State University Monterey Bay, California Department of Fish and Game and the Monterey Bay Salmon and Trout Project.

Facility

SCL replaced obsolete facilities at Tiburon, California. The new state of the art 53,400 square foot facility was occupied in December 2000. Constructed at a cost of approximately $20 million, the facility includes: office accommodations for approximately 65 administrative and scientific staff; ultramodern biological and chemical laboratories that support cutting-edge analytical approaches, e.g., in biochemical genetics and otolith micro structural and micro chemical analysis; latest information technology infrastructure, e.g., copper, fiber-optic and coaxial cable drops in nearly every work space, LAN of latest PC and workstation platforms and peripherals to support computationally intense modeling analyses, connectivity to University of California system-wide networked assets such as on-line journals; environmentally friendly design; experimental seawater and freshwater aquarium systems with digital control of environmental conditions and an exterior captive broodstock facility where large volume experiments can be conducted; digital and motion sensor control of the environment in all interior spaces; digital imagery laboratory for analysis of *in situ* video, acoustic and electro-optic imagery for seafloor mapping and GIS georeferencing and layering.

Approximately $2.5 million worth of improvements to the facility will be completed by the summer of 2003 including: carpeting of all common areas; addition of 8 offices, 15 office cubicles and 2 dry laboratories; improved landscaping; additional parking; completion of the seawater system and construction of a captive broodstock facility.

Staffing

There are about 55-60 total staff members, including 42 permanent federal FTE (5 administrative, 2 information technology and the balance scientific) and 15-20 temporary scientific support staff. We are in various stages of recruiting for an additional 6 vacant permanent federal FTE. The expertise of the staff is mainly biological (population dynamics, stock assessment and extinction risk modeling, genetics and molecular ecology, fishery oceanography, ecology, physiology and behavior), but also includes resource economics. Approximately one-half of the scientific staff hold Ph. D. degrees.

Pacific Fisheries Environmental Laboratory

Partnerships

Ocean data: PFEL's principal collaboration is with FNMOC. FNMOC, the primary U.S. Navy facility concerned with marine weather and ocean conditions and the terminus for the Navy's global environmental data network. These data, along with their advanced models for operational oceanographic and atmospheric prediction, serve as the basis for much of PFEL's data product suite. PFEL also serves as the archive for these important historical data files. Our ocean data role also results in significant collaboration with other NOAA line offices, including OAR (Pacific Marine Environmental Laboratory) and NESDIS (National Oceanographic Data Center, Climate Diagnostics Center), and more recently with the California Department of Fish and Game. PFEL now can serve and exchange data within the Distributed Oceanographic Data System (DODS). We also are developing and hosting web pages and Live Access Servers (LAS) for collaborative programs (e.g., SAIP, TOPP).

Research: Research collaboration is at several levels. Within the SWFSC, our collaboration is with the Santa Cruz Laboratory and the La Jolla Laboratory, and with the Honolulu Lab, although they are no longer within the. Elsewhere in NMFS, we have collaborations with the NWFSC, AFSC, and NEFSC. On the regional level we have extensive collaboration with the Naval Postgraduate School in our GLOBEC Northeast Pacific research program as well as with other institutions. Because of the nature of PFEL's research mandate and the broad geographic scale of our work, we also have several international collaborators. This has been a long traditional at PFEL, and currently includes participation in comparative EBC research sponsored by IAI-EPCOR, IRD, and FAO, and with individuals from a number of countries.

Facility

The PFEL facility located in Pacific Grove, California is a three-story, 13,800-square-foot structure on 4.28 acres of land that was originally acquired by the U.S. Government for the adjacent Point Pinos lighthouse in 1901. The US Navy transferred the building to the National Oceanic and Atmospheric Administration (NOAA) in October 1996. PFEL, originally formed in 1969 as Pacific Environmental Group, moved into the facility in 1996 and has made significant improvements since then not the least of which have included the addition of new offices, office cubicles, modernization of computing facilities as well as enhancements to exterior areas and landscaping. The PFEL facility supports approximately 28 scientific and administrative staff and is also home to the West Coast Regional Node of the NOAA/NESDIS Coastwatch program. PFEL facilities have an efficient information technology infrastructure, NOAA-wide WAN, local LAN, multiple Live Access Servers (LAS) and web servers, modern computing workstation & multiple platforms (including PC, Macintosh, and Sun, SGI, and MacOS X UNIX) with peripherals to support computationally intense scientific analyses and research as well as numerous computer modeling and visualization software programs and languages (such as MATLAB, FERRET, IDL, SPSS, ArcGIS, GMT, many internally-developed programs, etc.).

Staffing

There are about 28 total staff members, including 15 permanent federal FTE (2 administrative, 4 information technology and the balance scientific) and 9 scientific support staff. We are in various stages of recruiting for an additional 2 vacant permanent federal FTE. PFEL facilities also house 1 individual each from the NOAA Office for Law Enforcement, SWC Protected Resources Division, NOAA Corps, and NOAA/NESDIS Coastwatch program. The expertise of the staff is diverse including biological (population dynamics, stock assessment and extinction risk modeling, fishery oceanography, and ecology), physical oceanography, and innovative proficiency in Data Service designs and computer programming. Approximately one-half of the FTE scientific staff hold Ph. D. degrees.

National Marine Fisheries Service
Santa Cruz Laboratory

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RESEARCH AND MANAGEMENT SUPPORT ACTIVITY REPORTS

Introduction

California is at the southern extreme of the native range of anadromous salmonids where environmental conditions are marginal for their existence, thus, there are only three species, chinook salmon *Oncorhynchus tshawytscha,* coho salmon *O. kisutch* and steel head trout *O. mykis*. Chinook salmon occur in the large river systems of California, for example the Sacramento- San Joaquin (Great Central Valley), Eel and Klamath-Trinity. The Central Valley alone contains four Evolutionary Significant Units (ESUs), the fall, late-fall, winter and spring, comprising the most southern population in their native range. There are two other ESUs, the Southern Oregon-Northern California Coastal and the California Coastal. All ESU's except the Southern Oregon-Northern California Coastal and the Central Valley Fall Run are listed as threatened or endangered under the U.S. Endangered Species Act (ESA). Chinook salmon support important commercial (4 million pounds annually in worth ca.$10 million) and recreational (150 thousand fish annually worth ca. $15 million over the last 10 years) ocean fisheries.

Coho salmon inhabit California's small coastal rivers and streams. Although their historic range extended south to the San Lorenzo River in Santa Cruz on Monterey Bay, the southern extent of the range is now Scott Creek approximately 15 miles north of Santa Cruz. There are two ESUs, the Southern Oregon-Northern California Coast and the Central California Coast, and both are listed as threatened under ESA. There has been no harvest of coho salmon in California since 1992.

Steehead trout mainly inhabit small coastal streams, although they also occur well inland in the Central Valley and Klamath-Trinity river systems. Their historic range was south to the Tijuana River in Northern Baha California, but today they range south to San Mateo Creek north of San Diego, and have been extirpated from many drainages in the southern California. Six ESUs are recognized, the Klamath Mountain Province, Northern California, Central Valley, Central California Coast, South-Central California Coast and Southern California, and all except the Klamath Mountain Province are listed as threatened or endangered under ESA.

Anadromous salmonids in California face both natural and anthropogenic threats to their persistence. Occurring at the southern extremes of their distributions, ecological conditions are marginal for their existence. Furthermore, the California environment is highly unpredictable, featuring extreme microclimate, extreme variation in the ocean environment (e.g., El Nino and the Pacific Decadal Oscillation) frequent disturbance from drought, flood and fire. Anthropogenic threats include: agriculture, forestry, development, dams, hatcheries and harvest. For example, the mainstem and tributary streams of the Sacramento and San Joaquin Rivers in the Great Central Valley have literally hundreds of dams and diversions that supply water to the populous urban areas of San Francisco and Los Angeles outside of the valley, and irrigate one of the most productive agricultural regions in the world.

Santa Cruz Laboratory
Fisheries Branch – Salmon Population Analysis Team

Introduction

The Salmon Population Analysis Team's (SPAT) conducts research relevant to the conservation and restoration and recovery of anadromous salmonids. The Team focuses on problems particular to California, which is at the southern end of the range for the focal species. SPAT's research interests and expertise cover four broad areas, including conservation biology, population ecology, spatial ecology, and these lead to the development and application of quantitative methods (Figure 1). Team members may typically engage in any or all of these areas. This integrated approach provides the Team with broad capabilities for bringing science to bear on applied ecological problems.

The Team's research and service activities are closely related to NOAA Fisheries management responsibilities under the Endangered Species Act (ESA) and the Sustainable Fisheries Act (SFA). Indeed, the formation of SPAT traces back to the rising need for scientific expertise related to population biology of California's anadromous salmonids in the mid 1990s. At that time, NOAA Fisheries (with the assistance of several SPAT members) began systematic, coastwide status reviews of 7 species of Pacific salmon and anadromous trout. The status reviews resulted in the identification of 57 evolutionarily significant units (ESUs), 27 of which were subsequently listed as threatened or endangered under the ESA. Effective management of these ESUs requires significant scientific input, and SPAT provides most of this input for the SWFSC.

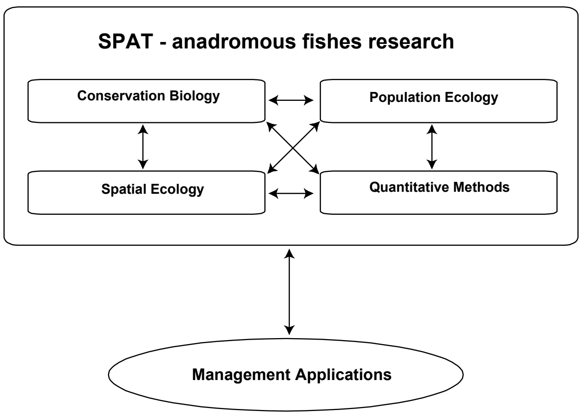


Figure 1. Schematic of the Salmon Population Analysis Team's (SPAT's) research activities and relation to management needs.

Team members provide scientific input to resource management by focusing a broad range of quantitative and field-oriented expertise and experience (1) to fulfill requirements for immediate analysis, and (2) to identify and attack scientific questions that address issues critical to improving ongoing and future management. Scientific service in support of management has, to date, dominated the Team's time and resources. These activities include (1) participating on numerous Biological Review Teams to assess the conservation status of anadromous fish throughout California and the Pacific Northwest, (2) leading and serving on four Technical Recovery Teams to develop the scientific underpinnings of recovery plans for listed ESUs throughout California and coastal Oregon, (3) providing analytical support and serving as technical advisors to the Pacific and Klamath Fishery Management Councils, and (4) working within NOAA Fisheries and with sister agencies to ensure consistency and rigor in management-oriented science.

In many cases, our service activities have inspired new research questions that broaden our scientific understanding of the life history and population dynamics of anadromous salmonids while having direct relevance to present and future management issues; these topics are described in some detail below under **Research Activities**. In other cases, however, we have been required to commit substantial time and energy to less scientific pursuits that at best lay the groundwork for more rigorous approaches in the future; these activities are reviewed below under **Advisory Support Activities**. We finish the review document with a discussion of **Future Research Directions** that address existing and emerging problems in the management of anadromous fishes in California.

There is significant feedback among four major areas (conservation biology, population ecology, spatial ecology, and quantitative methods) with needs or developments in one area driving progress in others. The linkage to management application is also significant—some research projects are a direct response to pressing management problems, while others are intended to improve future management capacity by developing information and approaches that managers do not yet know they need.

Research Activities - Conservation Biology

Much of our research is directly relevant to management of threatened and endangered salmonids. Most of this research is related to technical recovery planning; other work supports more general conservation efforts (e.g., *An Ecosystem Approach to Salmonid Conservation*), while still other work is in response to specific management problems.

Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units

In preparation for technical recovery planning, a conceptual framework for assessing ESU viability and predicting the characteristics of an ESU consistent with a negligible risk of extinction was developed, McElhany et al. (2000, see publication list). To do so, we synthesized a broad literature spanning conservation biology, ecological and evolutionary theory, and salmon biology. The framework that emerged from this effort focuses at the level of the population, explicitly recognizes the contribution of biological structure and variability within the ESU to viability of the ESU, and develops principles for assessing the viability of individual populations and integrating the status, distribution and diversity of populations to consider viability at the scale of entire ESUs. The core of this framework has provided a strong foundation for the activities of the Technical Recovery Teams and recent Biological Review Teams, yet has accommodated continued evolution of thinking on the conservation biology of anadromous fishes. In both informal and formal arenas, SPAT members have played a critical role in the ongoing development of these concepts and their application over the broad ecological range of anadromous salmon and trout.

Population Viability Assessments

We have completed several research projects in the area of population viability assessment (PVA), and will be applying these techniques in technical recovery planning. Lindley and Mohr (2003, see publication list) studied the effect of striped bass stocking on the viability of winter-run chinook salmon with a Bayesian predator-prey PVA model. This study showed that a proposed striped-bass stocking program could pose a significant additional risk to winter-run chinook salmon, which face a fairly high risk of extinction even in the absence of predation by striped bass. These results were influential in reducing the scope of the striped bass program.

We have assessed the viability of 20 populations of chinook salmon and steelhead in the Central Valley using a random-walk-with-drift-and-noise model, Lindley (2003, see publication list). According to this simple model (which ignores some significant extinction risk factors), most Central Valley salmonid populations are at some risk of extinction within 100 years. The only populations with negligible extinction risk are heavily supplemented by hatchery production. Results have been presented at several meetings and are in preparation as part of technical recovery documentation.

Identification of Historical Population Structure of Salmonid ESUs

We are bringing a variety of techniques to bear on the question of historical population structure of threatened and endangered salmonid ESUs in California and coastal Oregon. Historical population structure provides a critical context for recovery planning by establishing a baseline for which we can be most certain that an ESU was at negligible risk of extinction. Against this template, we compare current and possible future population structures, under the assumption that increasing deviation from historical conditions requires greater demonstration that a particular structure yields a viable ESU.

We are using a suite of approaches to estimate historical population structure in listed ESUs. Two approaches–collaborative investigation of population genetic structure, and analysis of correlations in time series of spawner abundance in a state-space modeling framework–are discussed in more detail in separate sections below. Two other methods are rooted in analysis of geographic information, and are supported by an in-house GIS. In both cases, we are examining the spatial distribution of spawning areas as a key determinant of reproductive isolation.

In one analysis, we use ordination analyses (Figure 2) to discern environmental differences between watersheds that might underlie differences in selective regime and drive local adaptation. Such differences provide useful information for discerning population structure, particularly divisions within major watersheds, and also support analysis of structure between the scales of the population and the ESU, which is relevant to ESU viability.

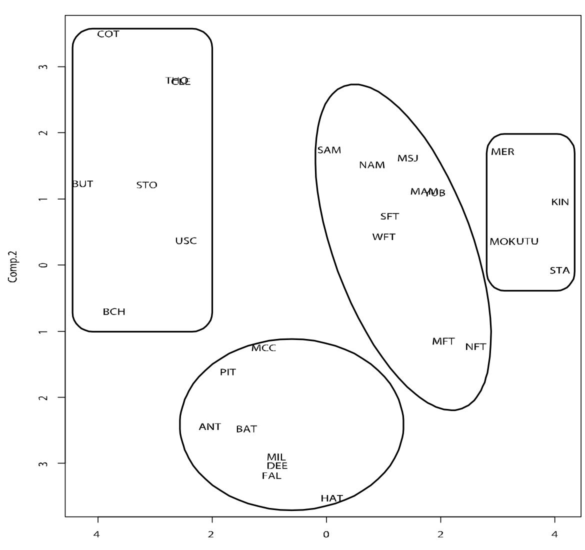


Figure 2. Principle components ordination of Central Valley (CV) spring chinook watersheds, based on physical habitat attributes. The 4 circled groups delineate diversity units identified by the CV TRT.

In the other analysis, we estimate the relative isolation of putative populations. Isolation is defined as the proportion of a spawning run expected to consist of individuals returning to their natal watershed, and is a function of size of a population and the number of immigrants to that population. The number of immigrants is a function of dispersal rates and the size of donor populations. We use GIS to estimate network distances between spawning areas from which dispersal rates are calculated using simple models of dispersal as a function of distance, and to derive proxy values for relative population size (e.g., see *Intrinsic Potential of Watersheds for Salmonid Production* below). This information is combined in a simple expression for the composition of each putative population. These results illustrate the strong relation between population size and isolation (Figure 3), but also demonstrate the importance of considering the spatial context of a population in analyses of population independence and connectivity in historic and current contexts.

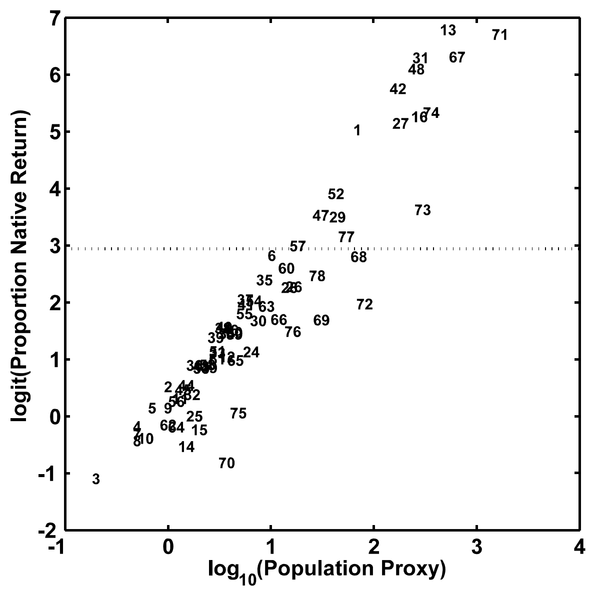


Figure 3. Relative isolation of coho salmon populations inhabiting watersheds along the Oregon Coast; higher values indicate greater proportions of native fish to spawning runs.

An Ecosystem Approach to Salmonid Conservation

In 1995, NOAA Fisheries, the U.S. Fish and Wildlife Service, and the Environmental Protection Agency oversaw development of a coordinated, region-wide strategy for developing, evaluating, and monitoring Habitat Conservation Plans (HCPs) prepared pursuant to the ESA; for fostering habitat protection and conservation on nonfederal lands beyond minimum ESA requirements and consistent with the mandate of the Clean Water Act; and for providing education and training in habitat protection and restoration strategies. The result of this effort was publication of "*An ecosystem approach to salmonid conservation,*" (Spence et al., 1996, see publication list), which has since guided conservation planning and evaluation of HCPs. A second edition of this document, "*Resisting Extinction: An Ecosystem Approach to Salmonid Conservation*", is currently being prepared by Team scientists. The revised edition incorporates scientific advances since 1995 and updates recommendations regarding development, evaluation, and monitoring of conservation activities based on practical experiences from ongoing efforts in the Pacific Northwest. *Resisting Extinction* comprises three parts. Part I describes the linkages between salmonids and their physical, chemical, and biological environment with an emphasis on landscape processes. Part II reviews the effects of human activities—including forestry, livestock grazing, agriculture, mining, urbanization, dams, water diversions, hatcheries, and harvest—on salmonids and their habitat. Part III proposes a strategy for conserving salmonid habitats in the Pacific Northwest and California, with an emphasis on nonfederal lands. We identify key issues relevant to conservation at the regional, watershed, and site levels, and recommend appropriate analyses and prescriptions for protecting salmonid habitats. *Resisting Extinction* will be published by the American Fisheries Society in 2004.

Geographic Variation in Genetic and Meristic Characters of Coastal Cutthroat Trout

This research is part of the completion of a doctoral research project begun at Oregon State University to examine geographic variation in genetic and meristic characters of coastal cutthroat trout (*Oncorhynchus clarki clarki*), and lays a conceptual framework for understanding how habitat variability influences the spatial distribution and persistence of populations at various spatial and temporal scales. This work, based on 55 populations sampled across their range (northern California to Prince William Sound, Alaska), represents the first range-wide description of the meristic and genetic variation in the sub-species.

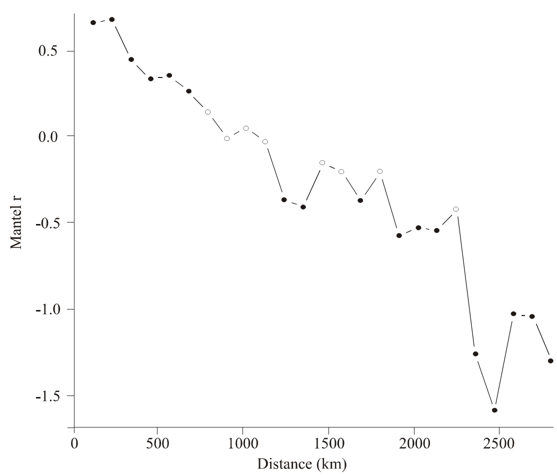


Figure 4 Correlogram illustrating correspondence between genetic distance and geographic distance. Data are from pair-wise genetic distances of 55 coastal cutthroat trout populations from across their distributional range; solid circles represent significant (*p* # 0.05) autocorrelation statistics.

Coastal cutthroat trout exhibited significant variation of meristic characters and allele frequencies across their range. Meristic characters did not reveal a latitudinal cline and provided insight to population structure at large spatial scales. Analysis of genetic data revealed geographic concordance of populations at the northern and southern extent of the subspecies range, and demonstrated isolation-by-distance at regional scales (< 800 km) (Figure 4). The primary structure of coastal cutthroat trout populations occurred at the individual stream level, and there was genetic affinity among populations at a regional scale. These results suggest that coastal cutthroat trout are characterized by many smaller, genetically more diverse local populations compared to other species of Pacific salmon and trout and provide a useful model for examining how small populations persist in dynamic environments.

Research Activities - Population Ecology

The origin of SPAT, as indicated by the name, was in studies aimed at the population level. While we have expanded our interests to include larger scales, population-level studies are still a major focus, including studies that examine how individual variability is integrated into population dynamics.

Life Cycle Studies of Coastal Salmonids

Populations of California *Oncorhynchus* are known to be highly variable in size, but the underlying mechanisms of this variation—climatic, human, ecological—and their timescales are unclear. None of these questions can be addressed without a detailed dataset describing the population structure of a salmon population over a long period of time. No such datasets exist for coastal California. To begin to alleviate this problem, the Team has recently initiated long-term studies of the South Fork of the Noyo River (Mendocino County) and Freshwater Creek (Humboldt County), both of which involve close collaboration with California Department of Fish and Game biologists (see also "*Survival of Coho Salmon in Habitats of Varying Quality*," below). We hope to initiate a replicate study in a southern California system.

The specific objective is to annually estimate the abundance of each life stage (adult, summer juvenile, outmigrant smolt) of each local *Oncorhynchus* species (coho and steelhead in the north, steelhead only in the south). Such data collection efforts require significant resources maintained over the long term, which is well-suited and appropriate for a government science agency. Over the short term, the data will be used to estimate trends in abundance, demographic parameters such as freshwater or marine survival, timing and distribution of spawning and rearing, and spawner stray rates. Over the long term it should be possible to study patterns of variability in each of these metrics.

For the South Fork of the Noyo, the research methods involve trapping adults in a fish ladder around an otherwise impassable dam. Counts are made continuously from mid-September until fewer than five coho are found in a week (i.e., spring). Summer juvenile counts and habitat data are collected using single-pass snorkeling throughout the watershed. Outmigrant smolts are caught in stationary traps during the downstream migration, from early March continuously until low catches or low streamflow occurs (usually by mid-June). Occasional high-water events require temporary removal of the traps. Results after three years of data collection indicate high variability and interesting patterns. For example, young-of-the-year coho salmon were almost four times more abundant in 2001 and 2002 than in 2000, while young-of-the-year steelhead had the opposite pattern: abundance was highest in 2000, with numbers decreasing by around 40% in 2001 and 2002.

Survival of Coho Salmon in Habitats of Varying Quality

Since 1998, we have been collaborating with researchers at Humboldt State University on a long-term project designed to examine habitat factors in northern California streams that affect survival of coho salmon during the freshwater phase of the life history. Currently, we are near the end of the fifth full year of sampling, and have collected information on abundance and distribution of spawners, redds, juveniles, and downstream migrants in a set of connected streams, one of which flows through pristine old-growth forest, and two of which have experienced recent disturbances such as logging or landslides. These data also include information on (1) how juvenile coho salmon use low-velocity overwintering habitats and the consequences of different habitats for growth and survival; (2) the existence and prevalence of a life-history variant that spends a second winter in freshwater, which had previously been undocumented in California; and (3) variation in fry production from redds as a function of habitat quality.

We have used data from this project to investigate ecological patterns and as the basis for development and evaluation of sampling schemes designed to estimate abundance or detect trends. One project has focused on analyzing patterns in the distribution of juvenile coho salmon among habitat types (e.g., pools, runs, and riffles) as a function of overall abundance to explore ecological dynamics to investigate the sensitivity of various metrics (e.g., presence-absence, mean density in a given habitat type, ratios of mean density across habitat types) to changes in abundance, and to examine the consequences of sampling error for the power of trend analysis. We are also investigating the causal mechanisms and viability consequences of the recently documented life-history variant using data collected on the prevalence of individuals that spend a second winter in freshwater, variability in watershed productivity, and density-dependence in juvenile growth rates.

Relationships Between Anadromous and Non-Anadromous Forms of Rainbow Trout

The species *Oncorhynchus mykiss* ranges further south than other anadromous salmonids, and unlike most salmon, *O. mykiss* exhibits both non-migratory (resident) and anadromous (steelhead) life history forms. There are theoretical reasons to believe that this life history diversity may be important in the establishment and persistence of populations of *O. mykiss* in southern California, where freshwater habitats and their connectivity to the ocean are relatively ephemeral. Identifying the roles of the two life-history forms has been difficult, in part because juveniles of the two forms co-occur and look identical. Otolith microchemistry is a potential tool for resolving this ambiguity, because the strontium-to-calcium ratios laid down in each year's growth of a fish's otolith can be interpreted as a record of the time it spent in freshwater versus marine habitats. We are using otolith strontium-to-calcium (Sr/Ca) ratios to identify life-history forms and estimate the proportion that are descended from females of the alternate form (Figure 5). We are interested in assessing the degree of reproductive isolation between the two forms. Future work will be closely coordinated with a project proposed in the Early Life History Team to investigate the role of environmental factors in determining anadromy/residency.

To date, over 2200 samples of resident and anadromous forms have been collected from many of the major rivers in northern California. Methods are being developed on these fish prior to using them on endangered ESUs in the south (the methods involve lethal sampling). We are analyzing these samples to compile a reference dataset, to confirm anadromy of steelhead broodstock, and to evaluate the use of scales and fin rays as non-lethal alternatives to the otolith-based method. These initial studies are quantifying basin-wide variation in the relative number of anadromous and non-anadromous progeny living below migration barriers, and whether this proportion covaries with either distance to the sea or the presence of large non-anadromous populations of *O. mykiss* upstream of nearby migration barriers. We expect the results to provide

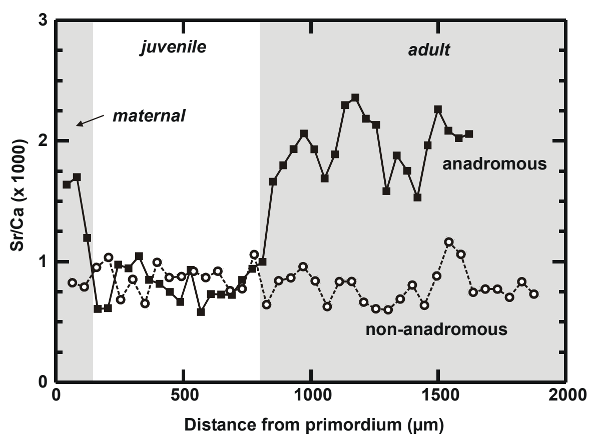


Figure 5. Cross-otolith patterns in Sr/Ca ratios of two adult *O. mykiss*. Sr/Ca ratios in the maternal region are higher in the progeny of anadromous females.

important guidance in recovery planning by clarifying the role of resident fish in population viability, population spatial structure, and diversity.

Research Activities - Spatial Ecology

Anadromous fish exhibit complex life cycles that play out across the land- and sea-scape. To restore, manage and monitor these fish effectively, we must understand the spatial structure of populations and ESUs, how this structure reflects and responds to dynamic processes in the physical and biological environment, how this structure filters the environment to yield the dynamics of anadromous populations, and how this structure will respond to global change.

Intrinsic Potential of Watersheds for Salmonid Production

We are interested in the historical distribution and abundance of salmonids, partly because this provides one measure against which current and future conditions can be assessed. Such information is usually lacking in California. A promising approach for increasing our understanding of historical distribution is through estimation of intrinsic habitat potential. "Intrinsic potential" is a measure of habitat suitability based on geomorphological and hydrological characteristics of a watershed. In collaboration with researchers at the U.S. Forest Service Pacific Northwest Research Station, we are adapting a model originally developed to predict distributions of coho salmon and steelhead in coastal watersheds of the Coast Range of Oregon, and using it to predict intrinsic potential habitat of the same species in southern Oregon and the California coastal region.

Intrinsic potential of individual stream reaches is defined to be a function of the combined influence of stream gradient, valley constraint, and discharge. The underlying model uses "fuzzy logic" that translates habitat characteristics into a measure of suitability for a particular species. Adapting this model to southern Oregon and the California coast has entailed (1) estimating a discharge-precipitation-catchment area relation for watersheds in southern Oregon and California, (2) conducting a literature review to confirm or modify the suitability curves that map habitat characteristics to habitat suitability (including preliminary development of suitability curves for Chinook salmon), (3) developing and evaluating a method for interpolating a comprehensive 10 m resolution digital elevation model (DEM) from the available 30 m resolution DEM, and (4) developing additional environment-suitability relations (e.g., summer temperature) to examine the effects of factors that become increasingly important towards the southern edge of species' ranges. The model does not predict abundance or population size. Rather it provides a prediction of relative habitat quality, which can be used

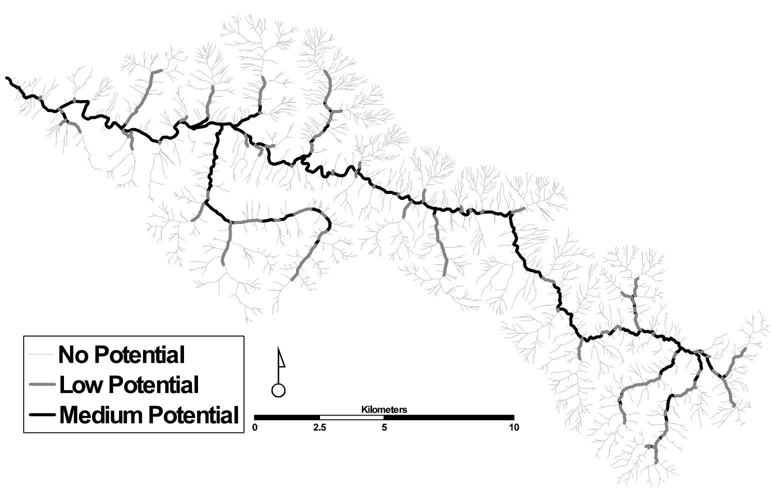


Figure 6. Intrinsic potential of coho habitat in the Bear River Watershed, California.

to compare locations within a watershed (Figure 6 shows an example), or to make approximate comparisons of the relative productivity of different watersheds.

Distribution of Steelhead in Central and Southern California

Basic information on the contemporary distribution and abundance of steelhead in central and southern California is extremely scarce. As a first step in filling this critical data gap, we are conducting an ongoing regional-scale survey of presence or absence for each coastal basin in which the anadromous form of the species historically spawned and reared. To resolve within-basin patterns, the largest coastal basins were subdivided into principal sub-basins. Survey results show that juvenile steelhead occur in nearly every basin to which they have access, even quite small ones with only a few hundred meters of spawning or rearing habitat between the ocean and the first impassable migration barrier. With few exceptions, steelhead populations were only absent from watersheds from which they were excluded (either by barriers, or by de-watered mainstems). This suggests that the overall metapopulation is not colonization-limited, but rather habitat-limited, with direct implications for recovery strategies for the species.

Green Sturgeon Migration and Estuary Use

While the bulk of our work is salmonid-focused, we are interested in anadromous fish in general, and have recently begun working on green sturgeon, a candidate for listing under the ESA. Green sturgeon aggregate in estuaries along the west coast (Figure 7) during the summer where they are vulnerable to bycatch in salmon gillnet and groundfish trawl surveys. Catches in these fisheries are the best indicators of green sturgeon abundance, but interpretation of these records is problematic because the origin of the aggregations is unknown, as is the fraction of the total population in these aggregations. We seek to determine the origin of green sturgeon in summer aggregations, the fraction of the population that is in estuaries during the summer, and the frequency of movement between estuaries and the coastal ocean. In collaboration with researchers at the NWFSC, Wildlife Conservation Society, USFWS, USGS, WDFW, ODWF, CDFG, Oregon State University, and UC Davis, we have initiated an acoustic and archival tagging program that will answer these questions. This project is funded by a competitive grant from the NOAA Fisheries Office of Protected Resources. Techniques and experiences from this project will be applied to salmonid questions as tags become small enough for application to salmonids.

Figure 7. Major rivers used by green sturgeon. Dots indicate locations of hydrophone arrays.

Research Activities - Quantitative Methods

Our research on quantitative methods supports, and is driven by, our work in conservation biology, population biology, and regional ecology. Research in this area falls into several categories: estimation of population size from survey data, analysis of population dynamics, decision support, and theoretical modeling of ecological systems. Much of this work entails a statistical approach; we are especially interested in characterizing uncertainty in data and model structure, integrating this uncertainty into our analyses, and developing rigorous methods to reduce this uncertainty.

Estimation of Smolt Abundance in Small Populations

Estimates of the abundance and characteristics of outmigrating smolts provide information on production during the freshwater phase of the anadromous life history. Rigorous mark-recapture techniques are already available for making such estimates, but the estimators require time-stratified study designs that are not always practical in the small, coastal populations typical of California. To make the estimators useful for monitoring small populations, we developed and tested an analytical method that aggregates stratified mark-recapture data as needed to obtain a useful estimate of abundance, while preserving as much of the structure of the data as possible (Bjorkstedt, in prep, see publication list). The analysis method has been made publicly available and is used by a number of agency, industry, and private biologists to estimate abundance from smolt mark-recapture data.

We are also pursuing ways to reduce uncertainty in population estimates arising from the artifactual mortality rates occurring in downstream migrant traps. This work was inspired by recent field studies conducted by collaborators at Humboldt State University, in which coastal cutthroat trout that enter traps were observed to consume substantially more juvenile coho and chinook salmon than they do under natural conditions. In collaboration with researchers at the California Cooperative Research Fisheries Unit at Humboldt State University, we are designing and evaluating the performance of new live-box configurations that efficiently and effectively segregate large, potentially predatory fish from juvenile salmonids, as a way to reduce the inflated predation mortality. Preliminary results suggest that a full mesh live box with a mesh divider panel is effective in segregating trapped fish by size; analysis of predator stomach contents is currently in progress.

Estimation of Juvenile Abundance in Small Streams

A variety of sample survey designs have been recommended for estimation of the abundance (or density) of juvenile salmonids in small streams. These designs typically first stratify the survey area into “natural” habitat units (e.g., runs, pools, riffles), and rely substantially on use of electrofishing removal methods to establish the abundance of fish in selected units. Extensive use of electrofishing is not without drawbacks however, and we have developed with colleagues at Humboldt State University “diver visual count” based survey designs and estimators appropriate for juvenile salmonids in small, clear streams. A stratified two-phase sampling design is proposed in which a large sample of habitat-specific units is selected in phase I, and divers make a visual count of the fish present in these units. Detection probability is addressed by taking a subsample of these units for phase II “calibration”, but rather than using electrofishing to estimate a unit’s actual abundance, a number of additional diver counts are made in these units and order-statistics are used to estimate a unit’s abundance. Overall abundance point and variance estimators were derived for this survey design, and their performance assessed via extensive simulations of repeated independent surveys applied to sampling universes constructed from empirical survey data for juvenile coho salmon in northern California (Hankin and Mohr, in prep, see publication list).

Analysis of Presence/Absence Data

The Team has recently developed methods for collecting and analyzing occurrence data, also known as presence/absence data. This kind of data is attractive for describing the spatial structure of animal species because it requires less sampling effort per-site to collect than abundance data and thus allows larger numbers of sites to be assessed per unit cost (an order of magnitude more sites in some cases). The problem with occurrence data however is in the interpretation of observed absences, because true absence is confounded with detection-failure. There is no standard analytic method for dealing with this issue, yet it is fundamental to all distributional studies. Based on the idea that the odds of true absence vs. detection failure should depend on the level of survey effort expended (amount of habitat searched), we have developed a statistical model for analyzing occurrence data. This model can be used to test the hypothesis that population density is greater than some small critical value u_{crit}, arbitrarily close to zero, using a dataset consisting solely of observed absences (Figure 8). Assuming no observation error within the sampled sites (detection if present), a simple rule of thumb emerges: to test the hypothesis of 1 or more animals per *y* km of a linear habitat such as a creek, search 5*y* km of habitat for an "=0.01 test, and 7*y* km for an "=0.001 test. This model has been generalized to allow for observation error within sampled sites, and to habitats better described as areas or volumes.

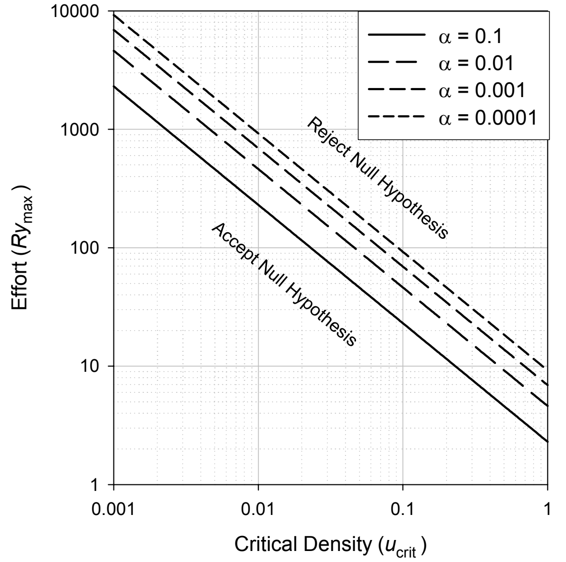


Figure 8. The survey effort required to reject the null hypothesis that a species is present in a stream system. R is the number of sites visited without observing the species, ymax is the length of stream surveyed at each site, and ucrit is a critical population density below which the species is considered to be absent.

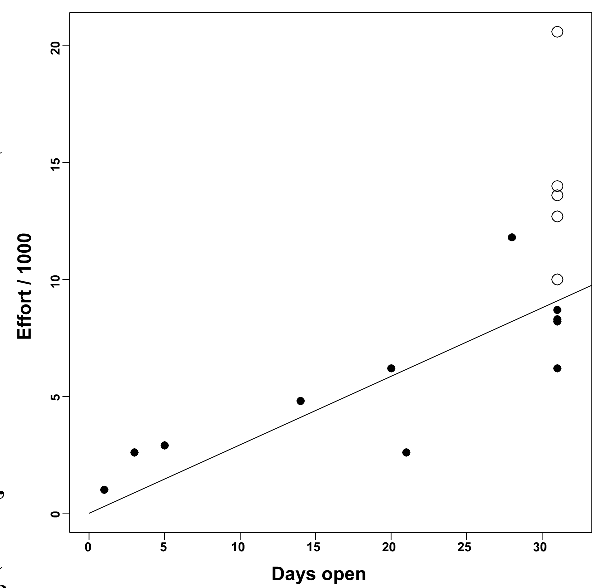


Figure 9 Recreational salmon fishing effort in Northern California during August versus days open in the month. Open circles indicate 1986–1990 data; solid circles indicate 1991–2000 data; line is ratio estimator fit to the 1991–2000 data.

The Klamath Ocean Harvest Model

Team scientists recently directed an effort by NOAA Fisheries and the California Department of Fish and Game to overhaul a harvest management model, the Klamath Ocean Harvest Model (KOHM), a cornerstone model used by the Pacific Fishery Management Council to achieve fishery conservation objectives for Klamath River fall chinook salmon. The KOHM predicts ocean time-area specific fishery impacts and harvest, Klamath River tribal and recreational impacts and harvest, and the numbers of fish returning to spawn naturally and at hatcheries in the Klamath River basin. The two most significant improvements we introduced to the KOHM were: 1) Development of a statistical model which allows for a rational analysis of the relationship between fishing season length and fishing effort over periods during which substantial changes in fleet size have occurred (Figure 9). This effort prediction model has since also been adopted for use as the basis for forecasting incidental ocean harvest of ESA-listed coho salmon. 2) Development of an explicit model for the number of Klamath fall chinook encountered by the fishing gear as a function of fishing effort. When coupled with the effort prediction model, this allowed for the use of all fisheries data collected since 1986. The previous model, developed in the late 1980s, was limited to the use of fisheries data gathered between 1986 and 1990, and relied on crude, and in some cases undocumented, methodologies to assess the large reductions in commercial fishing capacity that occurred during the 1990s. For our leadership and scientific contributions in this endeavor, Team scientists were awarded the Department of Commerce Bronze Medal in 2002 “For theoretical and methodological contributions which significantly advance the scientific basis for management of Pacific Coast salmon resources.”

State-Space Models

We are utilizing state-space models in a variety of work. State-space models allow process variation and measurement error to be handled simultaneously, a great advantage when one is interested in estimating parameters of a stochastic population model from noisy data. Our early focus was on estimating the parameters of a simple extinction model using noisy data (Lindley, 2003). The state-space approach offered improved performance over available alternatives (Figure 10).

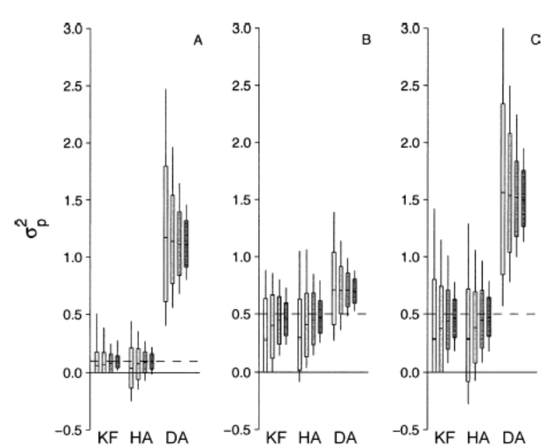


Figure 10. Performance of three process error variance estimators under different levels of process, measurement error, and time series length. KF: Kalman filter (state-space); HA: Holmes algorithm; DA: Dennis algorithm. A: small process error, large meaurement error; B: large process error, small measurement error; C: both errors large.

We are currently developing non-linear, non-normal state-space models for forecasting winter-run chinook juvenile abundance from time series of adult and juvenile abundance (Newman and Lindley, in prep, see publication list). Such forecasts are needed for managing water exports and other activities in the Sacramento River.

Other ongoing projects using state-space techniques include analysis of otolith increment and microchemistry data, analysis of coded-wire tag data to detect ocean climate effects on the growth of chinook salmon, and the use of multivariate models to test for migration among populations using spawner abundance time-series data.

Disturbance Ecology: Analysis of Correlation Scales in Freshwater Disturbance Regimes

Due to the importance of covariance among populations in predicting metapopulation dynamics, we are engaged in research activities to estimate the spatial scale and intensity of disturbances in local (freshwater) habitats. Our current emphasis is on the effects of streambed scour during flood events on reproductive success of coho salmon in coastal watersheds of southern Oregon and northern California. Our approach consists of (1) assembling and standardizing data on stream discharge at a daily scale for the portion of the year during which coho salmon spawn and eggs and fry are confined to the redds (nests), (2) calculating a suite of indices of integrated disturbance for each year of record, and (3) analyzing spatial and temporal correlations in the resulting indices of annual disturbance. We calculated five disturbance indices, ranging in complexity from a simple count of the number of flood events (contiguous periods of discharge exceeding a flood threshold), to a probabilistic model that integrates the proportion of redds scoured as a function of flood intensity and the timing of floods relative to the spawning season. Analyses of spatial correlation suggest that the spatial scale of flood-related disturbance is on the order of 250-300 km (Figure 11). Current work is focused on implementing this analysis in GIS to support more rigorous analysis of the spatial pattern in flood events and predicted redd scour. These results contribute to decisions regarding the spatial distribution of populations consistent with ESU viability.

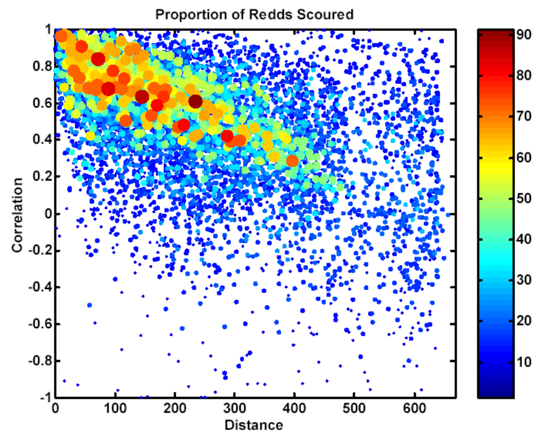


Figure 11. Spatial correlation of model predictions of redd disturbance during flood events.

Ecological Theory for Competing Metapopulations of Species with Complex Life Cycles

There is mounting evidence of competition among juveniles from different populations during their time in freshwater migration corridors and in marine habitats. This suggests dispersal is not the only way in which different salmon populations interact with one another. Metapopulation theory pertinent to this situation does not appear to exist yet. To fill this gap we are developing a theory of spatially-structured population dynamics for species with complex life cycles in which the populations occur in separate sites during some portion of their life history and share habitats during another portion. This research so far has investigated production functions involving temporally-disjoint density-dependence, e.g., concurrent effects of growth (fecundity) and subsequent competition for nesting sites on salmon production (Bjorkstedt 2000).

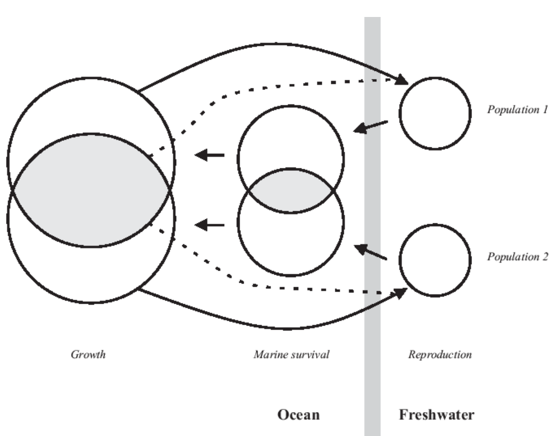


Figure 12. Schematic of competition within a salmonid metapopulation

Recent work has focused on (1) extending this theory to examine the consequences when populations both compete in a common habitat and also exchange individuals through dispersal (Figure 12), and (2) parallel development of stochastic patch-occupancy models that include phenomenological effects of competition. These analyses have yielded insight into the synergistic effects of competition and dispersal on the composition of populations, and the consequences of competition for the resilience of individual populations and extinction of the entire metapopulation. Anticipated contributions to management decisions include (1) predicting the effects of hatchery production and changes in ocean conditions on the dynamics of natural populations and metapopulations; and (2) predicting the effects of different restoration strategies, i.e., whether to improve habitat quality (productivity) or extent (capacity) in local habitats, for local and metapopulation viability.

Power Analysis

We developed a test for assessing whether a population has achieved a benchmark growth rate (Lindley et al., 2000, see publication list). The benchmark was set by ocean fishery managers, and we identified a deviation from this benchmark that corresponded to an unacceptable level of extinction risk using a simple population viability model. Statistical power analysis was then used to determine the "-level for a one sided *t*-test of the hypothesis that the population was meeting or exceeding the benchmark, with a specified power of detecting the biologically significant reduction in growth rate. For a given power, the necessary "-level declines with increasing numbers of observations (Figure 13).

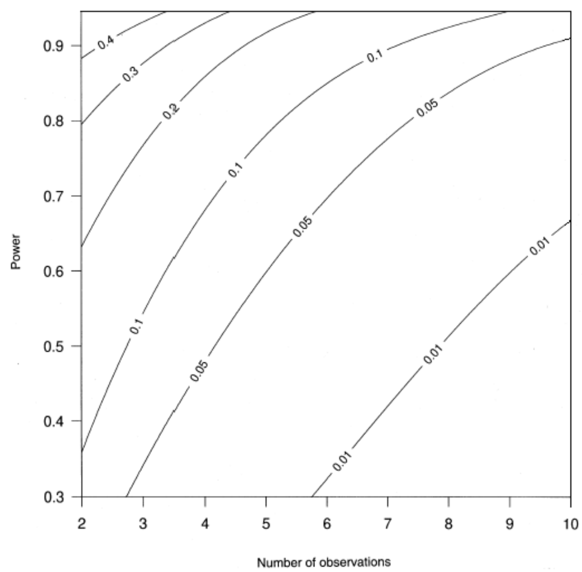


Figure 13. Type-I error rate (") of the proposed *t*-test as a function of the power and the number of observations.

Estimation of Hooking Mortality

Hook-and-release mortality has become an increasingly significant source of mortality in West Coast ocean salmon fisheries, given the depressed status of many Pacific salmon stocks. In the 1990s, a new fishing technique now known as "California-style drift mooching" became very popular among recreational anglers in the San Francisco and Monterey areas off California; a technique that results in a high proportion of gut-hooked fish. The Pacific Fishery Management Council initially assumed a hook-and-release mortality rate of 0.08 for this fishery, the same rate assumed for the recreational troll fishery. California Department of Fish and Game biologists invited Team scientists to collaborate with them on the design and analysis of a study to estimate directly the hook-and-release mortality rate associated with drift mooch fishing. In the study, a total of 276 chinook salmon were drift mooch-caught and held for four days in 8,700 liter onboard holding tanks aboard the *R/V Maiko* for wound location-specific mortality rate evaluation. Gut-hooked fish that survived the four day holding period, but whose internal organs were severely damaged, were considered mortalities. The control-adjusted, four day mortality rates depended strongly on hook wound location (Figure 14). The distribution of wound locations in the fishery itself was estimated based on a sample of 522 fish; the relative frequency of gut-hooked fish (0.41) was twice that of any other location. The fishery overall hook-and-release mortality rate was estimated to be 0.42 (95% confidence interval of 0.34–0.50), obtained by weighting the wound location-specific, four day mortality rates by the relative frequency of those wound locations in the fishery, and use of a sampling variance estimator derived expressly for this study design (Grover et al., 2002).

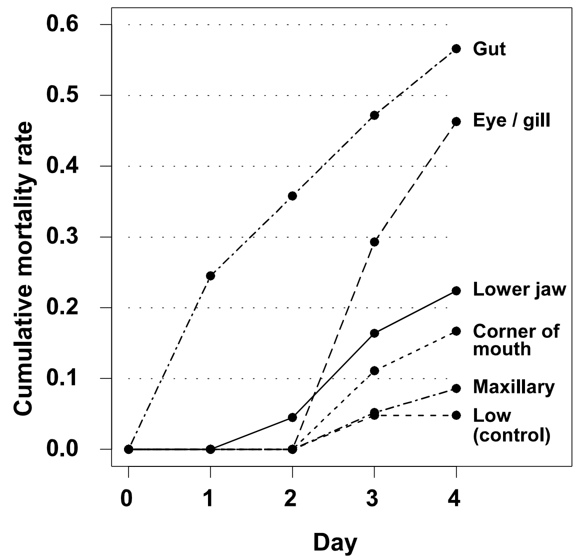


Figure 14. Cumulative mortality rate trends over the four day holding period by hook wound location category. Low category denotes a surrogate control group consisting of tank-held fish having no wounds or superficial wounds.

Genetic Evaluation of Visual Identification of Steelhead, Cutthroat Trout and Their Hybrids

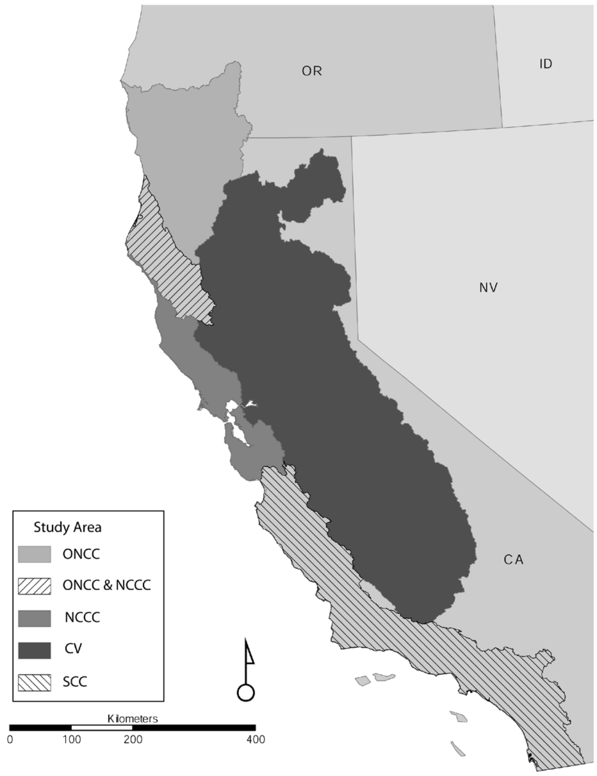
In contrast to surveys conducted for juvenile coho salmon, surveys designed to estimate juvenile abundance of sympatric steelhead and cutthroat trout are limited by the difficulties of distinguishing the two species (and their hybrids) during diver visual surveys and electro-fishing surveys. In collaboration with researchers at Humboldt State University, we have explored strategies to use genetic markers for evaluating the effectiveness of visual identification characters typically used in the field. Analysis of visual and genetic identifications (the latter based on seven single copy nuclear DNA markers) confirmed that visual identification was imperfect, and that performance deteriorated for small fish. Nevertheless, once quantified, we have shown that this variance can be included in the statistical design of two-stage sampling protocols to more rigorously estimate the abundance of steelhead in systems where they are sympatric with cutthroat trout.

Advisory/Support Activities

In addition to our basic and applied research to support restoration and recovery of anadromous salmonids, we have been and continue to be heavily involved in service activities that support management under the ESA and SFA.

Status Reviews

Team scientists are frequently called upon to serve on Biological Review Teams (BRTs), the mechanism by which NOAA Fisheries assesses extinction risk under the Endangered Species Act. Biological Review Teams are convened by the Science Centers upon request from the Regional Offices of NOAA Fisheries, and they are composed primarily of scientists from the Science Centers (occasionally they include scientists from other agencies, such as the USFWS). Status reviews are written by selected members of the BRTs, and on the basis of these reviews the BRTs make recommendations to the Regional Office as to whether a given species, subspecies, or ESU is in danger of extinction, or likely to become endangered in the foreseeable future. The preparation of status reviews requires a significant time commitment devoted to gathering and analyzing data, presenting results to the BRT, and subsequent shepherding through an inter-agency peer-review process and final publication.



In the past 5 years, Team scientists have participated on BRTs evaluating the extinction risk for 28 ESUs or species of anadromous fish, and prepared the Status Reviews/Updates for 13 ESUs. Ten of these were prepared in late 2002 in response to three recent developments: 1) a court case (Alsea Valley Alliance vs. Evans) that invalidated a legal distinction the agency had drawn between ESA protection of wild populations and hatchery populations; 2) a pending court case (Environmental Defense Center vs. Evans) that threatens to invalidate a similar legal distinction between ESA protection of steelhead (the anadromous form of *Oncorhynchus mykiss*) and rainbow trout (the freshwater-resident form of *O. mykiss*); and 3) significant new data that include larger adult run sizes for many populations. The resulting assessments of extinction risk for these 10 ESUs were unchanged from the conclusions of the original BRTs that convened in the 1990s to assess extinction risk, although recent increases in escapement in many ESUs were considered a favorable sign by the BRT.

Team members also reviewed the steelhead ESU inhabiting the Klamath Mountain Province of northern California, green sturgeon (*Acipenser medirostris*) (Adams et al., 2002), and updated reviews for coho salmon ESUs throughout coastal California. The latter effort was conducted to support the State of California, which was considering listing the ESU as endangered under the California State Endangered Species Act.

Technical Recovery Planning

Recovery planning for listed ESUs of Pacific salmon and steelhead is a very large task, and the Team bears the primary responsibility for initiating and leading the scientific aspects of the undertaking in California. Termed “Phase I” recovery planning, this work is intended to inform and support the development and implementation of recovery actions (“Phase II”); the responsibility of the NOAA Fisheries Regional Office.

To make recovery planning more tractable, it has been organized around Recovery Domains that span the geographic range of one or more ESUs. Four of these Recovery Domains are partly or entirely included in California (Figure 15):

- *Oregon-Northern California Coast* (ONCC), which spans the range of the Oregon Coast Coho Salmon ESU and the Southern Oregon-Northern California Coast Coho Salmon

ESU and includes watersheds from the Nehalem River in Oregon (just south of the Columbia River) to the Mattole River in California;

- *North-Central California Coast* (NCCC), which spans the ranges of the Central California Coast Coho Salmon ESU, the California Coastal Chinook Salmon ESU, and the Northern California Coast- and Central California Coast Steelhead ESUs, and includes watersheds from Redwood Creek in Humboldt County to Aptos Creek in Santa Cruz County;

- *Central Valley* (CV), which spans the range of the Central Valley Spring-Run Chinook Salmon ESU, the Sacramento River Winter-Run Chinook Salmon ESU, and the Central Valley Steelhead ESU, and includes watersheds throughout the Sacramento-San Joaquin drainages; and

- *Southern California Coast* (SCC), which spans the range of the South-Central California Coast and Southern California Coast Steelhead ESUs, and includes watersheds from the Pajaro River to the U.S.-Mexico border.

SPAT scientists chair and serve on technical recovery teams (TRTs) for each of these domains. A TRT consists of 8-15 scientists nominated from federal or state agencies, academia, and the private sector, and is assigned to fulfill Phase I tasks for its specific Recovery Domain. SPAT also provides the TRTs with extensive research support.

The TRTs are engaged in identifying biological viability criteria for listed ESUs of Pacific salmon and steelhead throughout California. To do so, each TRT is committed to working through a sequence of steps:

1. Identify the historical and current population structure of each ESU, with particular focus on identifying "independent populations", as defined in *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units* (McElhaney et al., 2000);

2. Assess the status of each population with strong emphasis on independent populations; and for each population, identify viability criteria based on abundance, productivity, spatial structure and diversity which, if met, are expected to yield an acceptably small (5%) probability of extinction over 100 years in the face of "normal" environmental variability;

3. Identify various "viable ESU scenarios", or population configurations centered on independent populations, that are expected to yield negligible extinction risk for the ESU in the face of local or regional catastrophes and maintain the evolutionary potential of the ESU; these analyses are based on integrating contributions of population viability, location, and diversity to ESU viability; and

4. Identify data needed to reduce critical uncertainties and test central hypotheses, to assess the effects of recovery efforts, to measure progress towards recovery, and to provide guidance to research and monitoring efforts intended to collect these data in a rigorous way.

To date, the TRTs have focused on assembling and analyzing available data to identify populations that comprise each ESU, and to evaluate their degree of independence. Due to the lack of a coordinated mechanism for data collection and assembly in California, this effort has consumed considerable time and energy. SPAT has also committed substantial time and energy to developing and maintaining the "infrastructure" of technical recovery planning. These efforts include:

- Intra-agency collaborations that have guided and shaped technical recovery planning, including development of the *Viable Salmonid Population* conceptual framework (McElhaney et al., 2000), and engaging in efforts to implement consistent approaches to recovery planning in the face of regional differences in ecology and in available datasets;

- Assembling a GIS to support TRT analysis, much of which is spatial in nature (e.g., the cornerstone task of identifying the historical and current population structure of listed ESUs). The GIS contains information on hydrography, stream flows, topography, climate, land use/land cover, geology, ecological zones, infrastructure, barriers, etc., and employs a dynamic segmentation data model to assemble information on fish distribution, the location of barriers and gages, etc., in relation to hydrographic structure; and

- Assembling and managing a staff of four analysts who conduct statistical analyses in a spatially explicit framework, and four support staff who obtain, assemble and organize available data from a broad range of sources.

The TRTs that have been functioning since early 2002 (ONCC and NCCC) expect to complete their work in mid- to late 2004 . The CV-TRT and SCC-TRT anticipate more rapid progress by taking advantage of the established infrastructure and lessons learned by preceding TRTs, yet are expected to require 18 to 36 months to fulfill their tasks. SPAT scientists currently serving on the TRTs expect significant additional demands on their time in the future to provide scientific support to Phase II recovery teams, which are separate entities responsible for developing and implementing recovery plans.

Coastal Salmonid Monitoring Plan

We are working with the California Department of Fish and Game to develop a California coast-wide monitoring plan that will assess the status and trends of ESA-listed salmonids and measure progress towards recovery goals. The Salmon Restoration Grants Program is funding this project, which will involve a series of workshops to gather input from federal and state biologists, followed by the development of a statistically rigorous stratified sampling plan and associated estimators. The purpose of this plan ultimately is to provide the datasets that will be necessary to remove listed salmonids from the Endangered Species List if and when they recover. This work is a direct outgrowth of the participation of SPAT in Biological Review Teams and Technical Recovery Teams as described above.

Harvest Management

We participate directly in the Pacific Fishery Management Council (PFMC) and Klamath Fishery Management Council annual processes that develop regulations for the west coast ocean salmon fishery. As members of the Councils' Salmon Technical Teams, this includes annual review of ocean salmon fisheries data, updating of various databases, forecasting abundance, numerous public meetings, and quantitative analysis of the effects of alternative regulation scenarios (time-area closures, quotas, gear restrictions, size-limits, bag-limits, etc) on stocks under PFMC management as well as ESA-listed stocks. In addition to these activities, SPAT scientists provide scientific guidance to the NOAA Fisheries Southwest Regional Office on the development of Biological Opinions and harvest Consultation (jeopardy) Standards for ESA-listed stocks, and are participating on a scoping team considering an amendment to the PFMC salmon fishery management plan that would set conservation goals for Sacramento River winter-run chinook and Central Valley spring-run chinook.

California Hatchery Review

The California Department of Fish and Game and NOAA Fisheries conducted a joint review of California's anadromous fish hatcheries (CDFG and NMFS 2001). SPAT members participated in this review to satisfy an ESA-mandated evaluation of effects of hatchery operations on listed species, to determine whether such operations need to be authorized under the ESA. The major conclusions of the review were: (1) Central Valley fall- and spring-run hatchery Chinook salmon should be released "on-site" and not trucked to distant downstream sites; (2) a formal process should be identified for the periodic review and assessment (e.g., every 6-9 years or 2-3 brood cycles) of hatchery production levels; (3) a constant fractional marking program should be established at all hatcheries; and (4) Hatchery and Genetics Management Plans should be developed for each hatchery.

Future Research Directions

We are developing a strategic research plan that exploits the Team's broad capabilities and focus, and that continues to pursue a useful combination of empirical work, theoretical study, and rigorous statistical analysis. The Team has several developing lines of research:

Population Dynamics Data

The primary effort of the Team here will be to foster and develop long-term salmonid population data collection within California. These are the essential information which will guide and monitor the recovery status of listed salmonids. These activities include both the collection of life-cycle data ourselves and the encouragement and planning of data collection by other groups and agencies.

Life history diversity

Salmonids, especially steelhead and chinook salmon, have complex life histories and exhibit great diversity in the expression of life history traits among populations and among individuals within populations. We hypothesize that such variability is important to the persistence of salmonid populations, particularly at the edge of their range. We seek to characterize this variability, understand how it relates to the unique environmental characteristics found in California, and explore the consequences of these relationships for the viability of populations. We will bring to bear state-of-the-art field studies, laboratory methods, analytical approaches, and theoretical synthesis.

Dynamics of small populations and metapopulations

Many populations of coastal steelhead and coho salmon may never have been large, yet it seems that they have persisted for long periods of time. We seek to understand the mechanisms by which such small populations persist in the face of extreme environmental variation. We are approaching this question through studies of population structure, migration, and habitat use, and by developing theory grounded in empirical observations.

Economics Team

Introduction

The Economics Team includes two permanent FTEs and a number of temporary positions filled by postdocs, students and GIS analysts. The Team focuses on providing data, methods and analyses needed to address economic issues associated with protection of salmonid stocks listed under the Endangered Species Act (ESA) and NMFS' fishery management responsibilities under the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). Team members disseminate research results in journals and at conferences. They also participate on advisory committees that make technical recommendations to fishery managers.

The Team's approach to data collection and research is highly collaborative. For instance, the salmon habitat restoration research conducted by the Team is intended to complement work being done by the SPAT in the area of recovery planning. Moreover, virtually all of the habitat-related economics research involves cooperative arrangements (i.e., sharing of costs, data, models and/or expertise) with agencies such as the California Department of Fish and Game (CDFG), Pacific States Marine Fisheries Commission (PSMFC), Jackson State Demonstration Forest and U.S. Forest Service (USFS). The Team's fishery data collection efforts are planned in close collaboration with economists from other NMFS regions and centers, the PSMFC and the Pacific Fishery Management Council (PFMC).

To augment its base budget, the Team routinely responds to solicitations for economic funding proposals from the Economics and Statistics Branch (ST1) at NMFS Headquarters. The Team has also been successful in obtaining research funds from the U.S. Department of Agriculture and CDFG.

The goal of the Economics Team is to provide economic data and research that enhance the ability of NMFS to carry out its management responsibilities under the ESA and the MSFCMA. The Team's specific objectives are:

- to address ESA requirements to estimate costs associated with implementing recovery plans for California salmonids listed under the ESA,
- to develop models that systematically address issues pertaining to how habitat restoration objectives can be met with limited resources,

- to conduct economic surveys that provide information on the range of fishing activities engaged in by fishery participants, the value of these activities and the characteristics of the participants,

- to develop analyses and models that address fishery management problems and provide insights into how fishing behavior and the economic value of fisheries are affected by economic, biological and regulatory factors,

- to provide economic expertise and advice to policy makers.

Research Activities - Habitat Restoration Costs

The ESA requires that recovery plans for listed species include "estimates of ... the cost to carry out those measures needed to achieve the plan's goals and to achieve intermediate steps toward that goal" (ESA, Section 4(f)(1)(B)(iii), p.13). Habitat restoration is expected to be a major component of the recovery plans being developed for ESA-listed salmonids in California. The Team has initiated a number of projects that are intended to facilitate estimation of habitat restoration costs.

California Habitat Restoration Project Database (CHRPD)

Data on habitat restoration projects in California are fragmented among different funding entities, not maintained in a standardized format and not readily accessible. The objective of this project is to obtain a comprehensive inventory of salmonid habitat restoration projects in California, and to obtain cost and other project-specific information that can be used, with other relevant data, to estimate models that predict habitat restoration costs. The PSMFC, in collaboration with the Team, has created the CHRPD - an Access 2000 database that provides a standardized structure for describing habitat restoration projects in terms of cost and other types of project-specific features. The PSMFC has spent the past few years working with major restoration funding entities in California to incorporate their restoration projects into the CHRPD. The CHRPD presently includes all restoration projects administered by CDFG's Fisheries Restoration Grants Program, the NOAA Restoration Center, the National Fish and Wildlife Foundation and the Cantara Trustee Council. Project data provided by the State Coastal Conservancy and CalFED are currently being added to the CHRPD. Contingent on funding, the PSMFC plans to continue expanding the CHRPD by adding new project data as they become available from cooperating funding entities and eliciting cooperation from additional entities.

Habitat Restoration Cost Workshop

Restoration practitioners have considerable knowledge and experience that would benefit the Team in their efforts to specify habitat restoration cost models. This project works to obtain advice from restoration practitioners regarding factors affecting restoration costs and the feasibility of developing standardized methods for estimating restoration costs on the scale of a watershed or ESU. In November 2001 the Team chaired a workshop attended by engineers, foresters, geologists, hydrologists, biologists and economists representing a variety of federal, state and local agencies and non-governmental organizations. Workshop presentations and discussions focused on cost issues associated with five types of restoration activities - road maintenance/decommissioning, riparian restoration, instream treatment, fish screens, and wetland creation/restoration. Final editorial changes are now being made to the Workshop Proceedings, after which the Proceedings will be printed and distributed to interested parties.

Salmonid Habitat Restoration Cost Models

The goal of this project is to use project-level data from the CHRPD (e.g., project cost, work type, location, "size"), in conjunction with other relevant data on landscape features and economic conditions at the project site, to estimate models that predict habitat restoration costs. The Team hired Kelly Hildner (a GIS analyst and Ph.D. graduate of UC Santa Cruz) to obtain spatial data on landscape and economic variables that are expected to affect restoration costs, link these variables to data on individual projects contained in the CHRPD, and estimate restoration cost models with the composite data set. Significant progress has been made in collecting data on landscape features (e.g., elevation, soil erodability, land use) and economic conditions (e.g., unemployment rates, wage rates in the construction industry) and linking these variables to the individual projects in the CHRPD. The work has been difficult and painstaking. The project data contained in the CHRPD, which were originally collected to suit the purposes of funding entities, are not necessarily well suited (in terms of completeness and level of detail) for estimating cost models. Issues have arisen with regard to the quality, completeness and timeliness of the landscape and economic information that are available from non-CHRPD data sources. Linking the CHRPD and non-CHRPD data has also been problematic, and various ad-hoc procedures have been adopted to resolve differences in spatial scale among the various data sources. Some preliminary model runs have been made, and the effort is continuing.

Research Activities - Quantitative Methods

Because of limited resources, salmonid recovery planning must be approached by strategically addressing problems that are most likely to benefit fish populations. The Team is engaged in a number of efforts to develop analytical techniques that facilitate identification of cost-effective approaches to salmonid restoration:

Optimization Models of Fish Passage Barrier Removal

The goal of this research is to apply operations research techniques to the problem of determining which fish passage barriers to address to maximize the habitat available to salmon with a limited budget. The Team, in collaboration with graduate student Jesse O'Hanley (Department of Environmental Science, Policy and Management, UC Berkeley), has developed exact dynamic programming methods and several heuristics based on greedy search algorithms to address the barrier removal problem. The algorithms have an explicit spatial dimension in that upstream barriers are not considered for removal if significant downstream barriers remain. Comparison of these algorithms to simple ranking and scoring procedures provides a measure of the degree to which barrier removal planning can be improved. Using data on fish passage barriers and GIS coverages provided by the Washington Department of Fish and Wildlife and Snohomish County's Surface Water Management Department, the algorithms were applied to four large watersheds in western Washington. The greedy-based solutions are significantly faster than dynamic programming on large problems, and perform much better than the scoring and ranking procedure. On average, the greedy algorithms produce 9% of the error of the scoring and ranking procedure, while their greatest departure from optimality is 11% of that of the scoring and ranking procedure. The Team is extending the algorithms to include sediment reduction as well as habitat expansion as criteria for barrier removal. The new algorithms will be tested using road erosion and fish passage data provided by the Mendocino County Water Agency's Salmon Habitat Restoration Program.

Optimization Models for Sediment Reduction from Logging Roads in Coastal California

This project is designed to identify state-dependent ('adaptive management') decision rules for sediment control measures in coastal streams. The Team has developed stochastic dynamic optimization techniques that provide decision rules for determining which treatment (status quo, road upgrade, road decommissioning) is likely to minimize the discounted cost of annual road maintenance, given the cost of each treatment and the extent of surface, stream crossing and landslide erosion volumes projected for the road. Graduate student Matt Thompson (Department of Industrial Engineering and Operations Research, UC Berkeley) provided significant assistance to the Team on the programming aspects of the model. We successfully applied the dynamic programming model to a case study road in Jackson State Demonstration Forest (JSDF). Model results were based on road maintenance cost estimates provided by JSDF and "expert opinion" and "rules of thumb" regarding the extent of landslide and surface erosion on the road. The Team is now extending the basic dynamic model to include a spatially explicit dimension that will provide decision rules for a network of roads. We are also collecting and analyzing the types of data needed to apply the spatial model to a road network in the Caspar Creek Watershed. For example, we constructed landslide time series parameters from landslide data obtained from the Caspar Creek Study, conducted by the U.S. Forest Service (USFS) Redwood Sciences Lab, and obtained access to the Watershed Erosion Prediction Project (WEPP), a model developed by the USFS in Moscow, Idaho that estimates surface erosion as a function of geology, climate and landscape. The Team has conducted actual road measurements in the Caspar Creek Watershed of the type needed to estimate the WEPP, and has produced the simulations needed to estimate road surface erosion dynamics in that watershed. The Team has obtained technical advice from the USFS in Boise, Idaho regarding road erosion measuring devices, and secured funding for the purchase of such devices in JSDF. JSDF is installing and will be monitoring the output of these devices. The data provided by these devices will allow for empirical validation of road erosion estimates obtained from the WEPP. Teresa Ish (a recent masters graduate from UC Santa Cruz) is contributing significantly to this project by enhancing the programs written by Matt Thompson, conducting the WEPP simulations and working on other technical aspects of the spatial model. Postdoc Sam Pittman (Department of Forest Operations Research, University of Washington) will begin working with the Team this fall on developing watershed-level models of salmon habitat enhancement under multiple objectives (sediment control, fish passage barrier removal, timber production, recreation, etc.). Pittman is an expert on methods of breaking complex problems into simpler components and integrating the components into a single model. The hope is that he will be able to take his modeling efforts from the watershed to the ESU level.

Optimization Models for Allocating Scarce Resources Between Monitoring and Restoration

Significantly more resources are dedicated to salmonid habitat restoration than to monitoring and evaluating (M&E) the effects of restoration. Therefore we began this project to develop optimization techniques that provide insights into how scarce resources should be allocated between M&E and restoration to maximize expected future restoration benefits. Models will be developed under alternative assumptions regarding the resources (time and/or money) needed for M&E to improve restoration methods and reduce uncertainty in restoration outcomes. The issue will be cast as a dynamic programming problem with two state variables (M&E and restoration). Teresa Ish (a recent masters graduate from UC Santa Cruz) will be working with the Team on this project.

Research Activities - Recreational and Commercial Fisheries

Management restrictions placed on one fishery may also affect fish stocks harvested in other fisheries (e.g., due to displacement of effort from the regulated fishery). To be able to evaluate both direct and indirect effects of regulation, economic surveys are needed that cover the entire range of activities engaged in by fishermen. The Economics Team has been actively involved in the planning and implementation of a number of economic surveys that cover non-salmon as well as salmon fishing activity in recreational and commercial fisheries:

Economic Valuation Survey of Pacific Coast Marine Recreational Anglers

The objective of this project is to obtain data needed to (1) characterize the recreational fishery in terms of fishing and expenditure patterns and angler demographics, (2) estimate the economic value of the fishery, and (3) predict the effects of regulations on angler behavior, and the value of the fishery. The economic survey was conducted as an add-on to the Marine Recreational Fishery Statistics Survey (MRFSS). Anglers randomly intercepted at fishing sites by MRFSS samplers were asked questions about their expenditures on the intercepted trip and if they were willing to participate in a follow-up telephone interview. The telephone interview included questions on angler demographics and non-trip-specific expenditures (e.g., annual expenditures on fishing gear and boats). The survey was completed in 1998. In 2002 the Team received funding to hire a postdoc to model angler behavior using the survey data. Information on the postdoc's work is provided below under "Behavioral/Valuation Model for Pacific Coast Marine Recreational Anglers".

Economic Impact Survey of Pacific Coast Marine Recreational Anglers

The objective of this project is to obtain data needed to estimate the economic impact of the recreational fishery on local economies. The sampling protocol used in this survey was very similar to the one described above for the 1998 economic valuation survey. The survey was completed in 2000. A report on survey results has been prepared by an NMFS Headquarters economist. The data are being used by the PFMC to estimate the economic impacts of recreational fishing.

Economic Survey of Pacific Coast Commercial Passenger Fishing Vessels (CPFVs)

This project is designed to obtain data needed to (1) characterize the CPFV fishery in terms of fishing patterns, revenues and costs, (2) estimate the economic value of the fishery, and (3) predict the effects of regulation on CPFVs and the value of the CPFV fishery. The

PSMFC created a license frame consisting of all state-licensed CPFV operators who participate in the marine recreational fishery in their state. Telephone interviews were conducted of CPFV operators randomly selected from the license frame. The survey was completed in 2002. Survey results are currently being summarized by the PSMFC. Contingent on funding, the Team would like to hire a postdoc to use the survey data to model the behavior of CPFV operators.

Economic Survey of Freshwater Salmon/Steelhead Anglers in California

The project objectives are to obtain data needed to (1) characterize the freshwater recreational salmon/steelhead fishery in California in terms of effort, expenditures and angler characteristics, and (2) develop models that predict how fishing effort on major salmon/steelhead rivers in California are likely to be affected by changes in hatchery practices. A PSMFC subcontractor will conduct telephone interviews of a random sample of steelhead report card holders, using telephone contact information obtained from CDFG's steelhead report card database. Because address/telephone contact information is not available for salmon anglers, the subcontractor will use a random digit dialing procedure to locate and interview freshwater salmon anglers residing in 23 central/northern California counties. The survey is expected to be implemented this fall, once OMB approval has been received.

Economic Survey of Pacific Coast Commercial Salmon/Groundfish/Crab/Shrimp Vessels (Initiated by NWFSC Economists in Consultation with Santa Cruz Lab Economics Team)

The project objective is to collect data needed to (1) characterize the behavior of participants in the PFMC-managed salmon and groundfish fisheries, as well as their participation in other fisheries (e.g., crab, shrimp), and (2) evaluate the effects of regulations on these fisheries. The PSMFC is creating a vessel directory that will contain contact information for all commercial fishing vessels on the Pacific coast. The survey instrument and the protocol for drawing a sample from the directory have not yet been finalized.

In addition to collecting fishery data, the Economics Team develops models that provide insights into the effects of biological, economic and regulatory changes on fishery behavior and the economic value of the fishery:

Investment (Entry/Exit) Behavior in the California Salmon Troll Fishery

The project objective is to assess the ability of financial models to explain how salmon trollers form expectations regarding future performance and how those expectations affect their entry/exit decisions over time. The Team has developed dynamic optimization models of adaptive behavior by fishermen, using option valuation techniques from mathematical finance. These models predict entry/exit behavior of salmon trollers, based on their individual performance and recent trends in fleetwide revenue. The models rely on proxies for harvesting costs (no cost data for the California salmon fishery are available) and characterize participation of trollers in non-salmon fisheries as "salvage value". The models can be tested by comparing predicted behavior to observed behavior. Using data for the period 1981-99, the current model predicts 60-80% of observed entry/exit decisions correctly, depending on model parameterization and the cost proxies used. The model is being extended in several ways. Rather than assuming that troller expectations are based on revenue trends, the model is being modified to distinguish between price (market) and quantity (stock) effects. Postdoc Valentina Bosetti (Department of Computational Mathematics and Operations Research, University of Milan) worked with the Team this past summer on developing the numerical routines necessary to treat the two state variables (price and quantity) simultaneously. This new approach may provide a means to link fleet dynamics models to models of fish population dynamics and extinction risk, as well as improve the predictive ability of the model. The approach is also expected to provide insights into the implications of vessel buyback programs by answering such questions as: How much is it worth to fishermen to have the option to fish when stock is x% higher than current level? How much worse would things have to get in terms of landings/prices to induce each vessel to leave the fishery? Beginning this winter, postdoc Vaishali Bakshi (Department of Economics, UC Irvine) will begin working with the Team on replacing the simplistic treatment of non-salmon fishing opportunities in the basic model with a more realistic representation of the alternative fisheries (e.g., groundfish, crab, albacore) typically pursued by trollers. Data to be gathered in the Economic Survey of Pacific Coast Commercial Salmon/Groundfish/Crab/Shrimp Vessels (cited above) will eventually be used to replace the cost proxies used in the current model.

Behavioral/Valuation Model for Pacific Coast Marine Recreational Anglers

The objective is to model recreational angler behavior and the effect of fishery regulations on such behavior. The Team, in collaboration with postdoc Deqin Cai (Department of Agricultural and Resource Economics, Oregon State University), has developed a random utility model (RUM) that depicts angler decisions regarding fishing mode, target species, fishing site and season. The model also predicts how effort would shift among modes, species, sites and seasons in response to specific types of fishery/area/season closures and the changes in economic value associated with such shifts. The postdoc has completed estimation of the RUM, using data collected in the 1998 economic valuation survey of Pacific coast marine recreational anglers and is now preparing a report summarizing model results.

Advisory/Support Activities

The Team expends significant resources on advisory/technical and management support activities including:

- Support of the PFMC in several capacities - as a member of the PFMC's Scientific and Statistical Committee (SSC), chair of the SSC's Marine Reserve Subcommittee and advisor to the PFMC's Ad Hoc Channel Islands Marine Reserve Committee.

- Serving as the SWFSC representative on the RecFIN Committee, which is comprised of representatives from NMFS, California, Oregon, Washington, PSMFC and PFMC. The RecFIN Committee's major role is to coordinate state-federal recreational fishery data collection efforts on the Pacific Coast and address technical issues associated with such surveys.

- Reviewing manuscripts and research, e.g., Sea Grant proposals and Saltonstall-Kennedy Grants as requested.

- Serving as the NMFS mentor for James Hilger (Department of Agricultural and Resource Economics, UC Berkeley), a recent recipient of a Sea Grant Graduate Student Fellowship in Economics.

- Consulting with other NMFS economists regarding survey content for fishery data collection efforts, developing sampling strategies, designing survey instruments, monitoring survey contracts and troubleshooting problems that may arise in the course of survey implementation.

- Support of other in preparing the extensive paperwork federal agencies to demonstrate that their public surveys meets requirements of the Paperwork Reduction Act.

- The Team spends considerable time recruiting personnel for postdoc and other temporary positions, writing funding proposals, and administering cooperative agreements and contracts.

Ecology Branch

The Ecology Branch conducts basic and applied research to increase understanding of the relationships between fishes and their environment, including distribution and abundance patterns, factors influencing growth and survival, habitat relationships, and community structure. This information is provided to fishery managers and the public via direct communication, reports, presentations, and peer-reviewed scientific publications. Three teams with the Ecology Branch conduct research on salmonids. The Salmon Ecology Team focuses on basic ecology and physiology of coho and chinook salmon and steelhead trout, and the influences of estuarine and marine conditions on interannual variability of stock status. The Molecular Ecology Team focuses on population structure and conservation genetics of ESA-listed salmonid populations. The Early Life History Team focuses on environmental factors determining growth and survival for age-0 steelhead, and plasticity in life history trajectories.

Early Life History Team

Introduction

Recruitment variability in marine fishes is generally thought to be a function of processes operating in the larval or early juvenile stages. Better understanding of these processes has tremendous value in predicting the abundance of an age cohort later in life (year-class strength), and for evaluating the potential impact of both natural and human-induced environmental changes on population dynamics. Despite extensive research efforts in this field in recent decades, definitive linkages between environmental patterns and larval/juvenile survival remain elusive. Complex interactions of spatial and temporal patterns in habitat quality, physical conditions, and the community structure of interacting species presumably contribute to the difficulty in resolving discrete causal relationships. The continuing threatened status of West Coast salmonid populations and the currently developing groundfish crisis warrant more intensive research into the array of factors driving early survival. Current projects being conducted by the Early Life History group focus on larval quality and growth rates as indicators of individual fitness. This individual variability provides the template on which mortality acts. Our research attempts to understand both the long term evolutionary selection pressures that maintain individual variability, and the short term ecological consequences for determining year-class strength.

Research Activities

Environmental correlates of life history trajectories in a wild population of juvenile steelhead

Steelhead exhibit remarkable plasticity of life history trajectories, with substantial variability in timing of juvenile smoltification and emigration to the ocean, timing of maturation, and timing of adult return. Presumably, maintaining this diversity of life histories is critical to the persistence of steelhead populations in a variable environment, and may be particularly important at the southern end of their range. The factors that determine life history trajectories are thought to include growth rates and condition (i.e., lipid storage), which are in turn affected by habitat quality (prey availability, temperature and fish density). Cohorts of Atlantic salmon, which have similar levels of variability in life history patterns, typically split into two size modes by their first winter, with the two modes diverging in behavior and growth during the winter, as well as emigration likelihood in the spring. These two strategies presumably trade-off growth with vulnerability to predation. It is unknown if these patterns occur in steelhead, although there is some evidence that individuals at the small end of the size range in the fall will not emigrate the following spring.

The objectives are to (1) determine if steelhead exhibit bimodal size distributions at the end of the first growth season, (2) determine patterns of density-dependent growth in natural habitats, and (3) test for contrasting growth strategies of different size and age classes. This field based study involves tracking growth and length-frequency distributions in a natural population of steelhead in Soquel Creek. Soquel Demonstration State Forest biologists have been sampling 4 sites via electroshocking in the fall since 1993 as a means of monitoring the population. They have made this data available to us. In 2002, we began assisting with their fall sampling, added an additional site, and have extended the work to earlier in the summer and later in the fall/winter to allow a better picture of temporal changes within a year. In 2003, the five locations will be sampled in early summer, early fall, and late fall or winter. Each includes depletion sampling with 3 electroshocking passes along a 100 yard reach of the stream. In 2003 all individuals captured during the early summer sampling were tagged. Fish < 80 mm in length were marked with an elastomer tag delimiting 7 size categories, and fish > 80 mm were injected with PIT tags. Scales were removed from fish >60 mm to determine age. In September, all five sites will be resampled, and examination of marked fish will give us estimates of growth by size category and retention within each site. Recaptures of PIT-tagged individuals will allow precise estimates of growth and any movement among sites. Sampling again in December will allow determination of contrasting summer and fall growth patterns and any indication of bimodal size distributions within the age-0 cohort.

Table 1. Total catch and proportion of age-0 fish (all individuals < 80 mm) in 100 yard reaches of Soquel Creek, sampled in the fall from 1993-2002.

Year	Amaya Cr.	Longridge	Spanish Ranch	Ashbury
1993			355 / 86%	
1994	13 / 61%	85 / 65%	184 / 69 %	98 / 42%
1995	8 / 0%	376 / 92%	335 / 92%	156 / 73%
1996	21 / 14%	349 / 87%	225 / 77%	103 / 36%
1997	62 / 65%	405 / 89%	394 / 94%	135 / 68%
1998	30 / 3%	433 / 85%	243 / 81%	88 / 54%
1999	82 / 62%	590 / 93%	429 / 86%	149 / 66%
2001	31 / 0%	489 / 88%	393 / 91%	194 / 70%
2002	40 / 35%	574 / 94%	412 / 92%	85 / 27%

September sampling will also be used to extend the time series initiated by State Forest biologists (Table 1). High consistency in both density and the proportion of the catch comprised of age-0 fish is evident across the 4 sites. Size distributions across each site (example in Fig. 2) also appear consistent across the time series. Where fall density is high, the population is comprised primarily of age-0 fish of very small size; in contrast, where density is low there are greater numbers of age-1+ fish and the age-0 fish present tend to be much larger. These patterns are suggestive of density-dependent effects on growth, survival, and life history trajectories; i.e, at locations with high density, growth is slow and survival of age-0 fish remaining in the stream also appears to be low, assuming that their absence a year later is due to mortality and not emigration. Sites with low density appear to have much faster growth rates based on the large sizes present at the end of the first summer, and the presence of a relatively high number of age-1+ fish in the following year suggests higher survival of age-0 fish that remain in the stream. These patterns require validation since the rate of age-0 emigration in the spring is unknown.

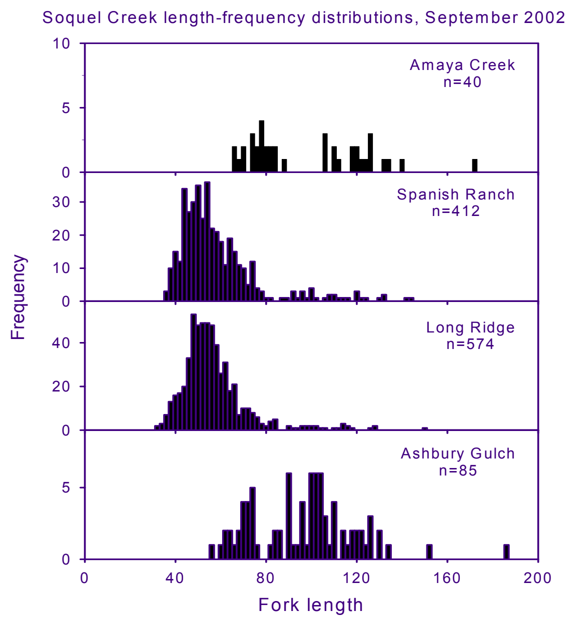


Fig. 1: Length-frequencies of steelhead (all age classes) at four sites on Soquel Creek.

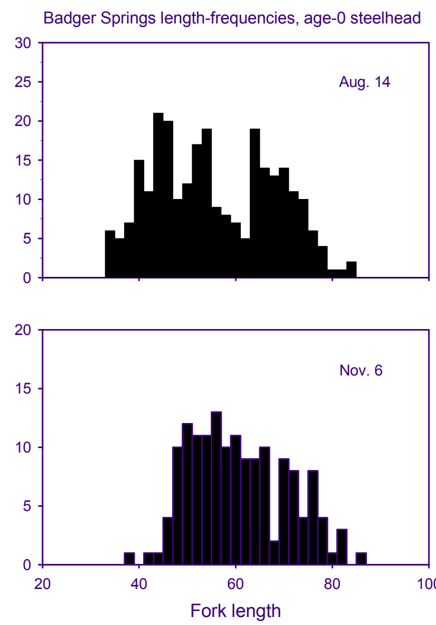


Fig. 2: Length-frequencies of steelhead (age-0 only) at Badger Springs in 2002.

Comparisons of length-frequency distributions of age-0 fish at one site in 2002 (Fig. 2) are suggestive of a bimodal distribution in August, but less so in November, counter to our hypothesis of developing bimodality as winter approaches. Sampling at all 5 sites in late 2003 will be useful in resolving this question.

Factors controlling behavior and smoltification rates in age-0 steelhead

Extensive work with Atlantic salmon has suggested that smoltification of age-0 individuals in spring is dependent on a developmental 'switch' occurring during a decision window in the prior fall; the switch is based on attainment of a threshold status of body condition or size. Once engaged, this developmental pathway tends to continue regardless of changes in body state subsequent to the switch; i.e., an individual programmed to transform and emigrate in the spring will continue on that pathway even if its growth suddenly declines, and an individual programmed to remain in the stream a second summer will continue to be anorexic even if foraging conditions suddenly improve. We predict that the similar life history plasticity of steelhead suggests similar determinants of life history trajectories. The project objective is to test for the influence of body size in the fall and discrete environmental factors on behavior during winter and likelihood of smoltification the following spring. We predict that size determines life history pathway regardless of events occurring during the winter, and that the designated pathway made by an individual influences its behavior.

This project involves laboratory experiments using steelhead from the Monterey Bay Salmon and Trout Project hatchery on Scott Creek. For the 2002 cohort, we examined the influence of body size and ration on behavior and subsequent seawater readiness in the spring. Fish from the San Lorenzo River population were raised in a single hatchery tank and fed an *ad libitum* ration throughout the summer and fall. In December, we set up fish in groups of five in our laboratory tanks. We used fish from the tails of the size distribution to examine the extremes of large (range 138-187 mm) and small (range 70-103 mm) body size. Fish received either high (ad libitum) or low (near maintenance) rations, with 5 replicates of each size/ration treatment. Temperatures and photoperiod matched those occurring in local creeks. Growth rates were monitored by measuring fish every two weeks throughout the winter. In March, behavior was assessed by videotaping two fish from each replicate group for four 30 min periods, two at night and two during the day. Measures quantified included the percentage of time spent actively swimming, the percentage of time spent hiding in a shelter placed on the bottom of the filming tank, and the total number of chases observed. In May, all fish were measured for a final time and a small section of gill filament removed for an assay of Na^+, K^+-ATPase activity. A value of > 3.0 :mols ADP/mg protein/ hour was used as an index of impending smoltification.

Growth rates of all fish in the lab experiment were low, likely in conjunction with the low temperatures (9-10 ºC). Ration level had a clear effect, with fish on low rations typically maintaining body size with minimal growth, and fish on high rations averaging 0.5% d^{-1} for specific growth in weight. All groups had reduced growth during the final interval prior to conclusion of the experiment in April. Initial body size and ration both influenced our measures of behavior. Fish in all four treatment combinations were more active at night than during the day, although this effect was more pronounced in small fish. In conjunction with lower activity levels during the day, use of the shelter was higher across all groups than at night, with fish spending on average 30% of their time in the shelter by day and 10% at night. This behavior typically resulted from one fish occupying the shelter at any one time. Chasing behavior was also influenced by fish size, with small fish engaging in significantly more chasing, and with more chases at night than during the day. The minimal aggression displayed by large fish did not differ between time periods. A pattern of higher activity at night and sheltering during the day is identical to that observed for Atlantic salmon held at winter

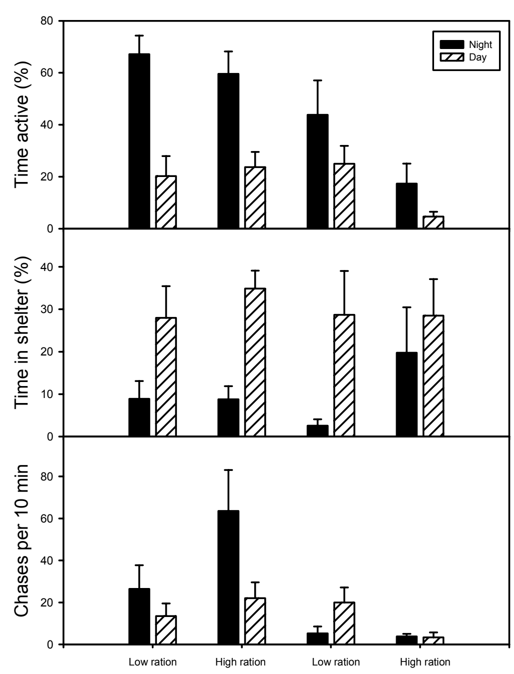


Fig. 3: Behavioral measures for small and large steelhead maintained on low and high rations.

temperatures, but higher chasing at night was opposite to our expectations, as was the higher activity level of small fish. We had predicted that fish on a trajectory to remain in the stream (i.e., all of the small fish) would have reduced activity compared to those predicted to emigrate.

Our index of seawater readiness (Na^+, K^+-ATPase activity) clearly differed between size classes, with no small fish exceeding the criterion value of 3.0 for enzyme activity (Fig. 3). For small fish, this result supported our prediction that fish destined to stay behind the stream for the following summer would not change their strategy if foraging opportunities improved. For large fish, the high level of seawater readiness for fish held on high rations (76%) concurred with our predictions, but the reduced proportion for large fish on low rations (43%) suggested that some individuals reverted to the non-emigrating strategy when foraging success declined. In the life history modeling framework, this result suggests that a second decision window occurs in which the decision to emigrate is switched off if performance declines.

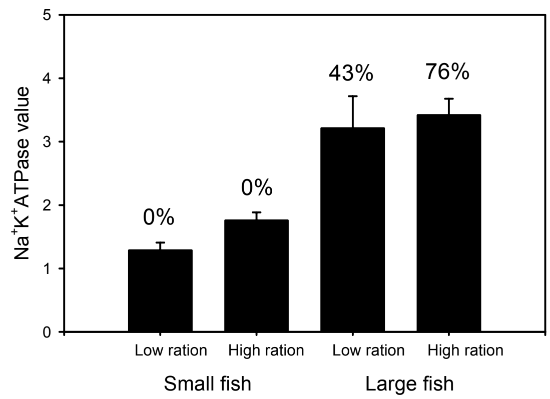


Fig. 4: Mean (+S.E.) activity levels of Na+K+ATPase for steelhead sampled in April 2003. Values above are percentage of fish with activities exceeding 3.0.

Future Research Directions

The two projects outlined above are in their initial stages of development. We plan to continue them as currently designed and expand where appropriate. For the field study of growth patterns and density-dependent effects, potential expansions include monitoring additional watersheds and increasing sampling effort on Soquel Creek to examine adult returns of PIT-tagged fish. Ongoing studies being conducted on Scott Creek by the Salmon Ecology Team directly complement this study and we will continue efforts to match data collection methods and approaches, and coordinate our research goals. Expansion of the laboratory study on growth and subsequent smoltification will involve monitoring of growth earlier in the summer (before the wide spread in age-0 sizes develops). This work is now underway with our 2003 experimental efforts. In addition, we will verify the utility of the ATPase enzyme analysis as a proxy for smoltification by conducting seawater challenge tests with all fish.

Additional new projects we would like to pursue include the following:

Creating steelhead from rainbow trout - defining the environmental conditions promoting anadromy

Genetic evidence suggests that for many watersheds the distinction between steelhead and rainbow trout is a function of physical barriers to movement rather than genetic differentiation between life histories. If physical barriers are removed, what is the likelihood of resident trout adopting an anadromous life history? If the tendency to undergo smoltification is a function of a particular set of environmental conditions, it may be possible to identify those conditions and develop management strategies the increase the proportion of anadromy in a population. A broad suite of environmental drivers may impact this life history decision, including fish density, food availability patterns, temperature regimes, rearing habitat characteristics, flow regimes, etc. This project would use a stock with minimal evidence of genetic segregation to evaluate the effects of different environmental parameters on life history.

The objective will be to determine the effect of specific factors on growth and smoltification in presumed non-anadromous vs. anadromous *Oncorhynchus mykiss*. Individuals derived from steelhead and rainbow parents would be raised in the laboratory under similar conditions and compared in their behavior, growth, and seawater readiness. The likelihood of emigration at different time periods would be monitored by using ATPase enzyme activities and seawater challenges. Growth rates will be manipulated using varying temperatures and ration levels. Stress levels will be manipulated using different fish densities and size groupings. We will coordinate efforts with ongoing research being conducted by the Salmon Population Analysis Team in a project using otolith core Sr/Ca ratios to derive maternal life history types.

Effects of temperature extremes on growth, survival, and behavior of juvenile steelhead

Water temperature plays a major role in driving various physiological and ecological processes in all teleosts, and therefore is a major determinant of habitat quality in rearing streams for steelhead. Management decisions for California steelhead regarding acceptable thermal limits and general temperature regimes are currently based on data derived for populations residing in more northern regions of the species range. Although it is often assumed that southern residents will have evolved adaptations to local conditions, such temperature relationships have not been rigorously tested and are currently unknown for California ESUs. This information is particularly relevant for management issues such as minimum flow requirements, sandbar breaching, quantification and mapping of suitable habitat, etc. In addition, a better understanding of the ecological impacts of elevated temperatures is necessary on a long term basis for predicting consequences of climate change. Shifts in both summer and winter temperature regimes are likely to have significant effects on age-0 steelhead resident in local streams. For example, winter temperatures that are higher than normal may put fish at risk by increasing activity at a time when fish are normally sheltering in protective cover. Likewise, summer temperatures that are higher than normal may put fish at risk through direct effects on physiological processes of growth and survival. The objective is to experimentally test the effects of high and low temperature extremes on steelhead from local populations. Laboratory experiments will be used to control the thermal experience of individual fish. Ideally such experiments will be conducted on fish from more than one population and with as wide a geographic range as possible to cover the potential spread in adaptation to different temperature extremes. This approach will also allow comparison with prior studies on more northern populations. Growth, survival, and behavior will be monitored, using methods we have developed during ongoing experimental work with steelhead. Interactive effects of temperature with other factors such as photoperiod, fish density, and food availability can be readily accommodated in our aquarium system. Manipulation of photoperiod, for example, may prove useful in evaluating seasonal differences in response to temperature extremes.

Salmon Ocean and Estuarine Ecology Team

Research Activities

Physiological Ecology of Juvenile Salmon in the San Francisco Estuary and Coastal Ocean

Chinook salmon populations from California's Central Valley have declined in recent decades. All four of the Central Valley chinook runs are listed or candidates for listing by the Endangered Species Act. Although freshwater diversions and habitat destruction contribute to population declines, it is becoming apparent that estuarine and ocean conditions may play a major role in the viability of this important socioeconomic resource.

Chinook salmon populations migrating through the San Francisco Estuary are at the southern limit of their range and are subject to the impacts of a highly urbanized, industrialized, and agricultural ecosystem. Climatic and oceanographic forcing affect environmental conditions and biological productivity that, in turn, influence salmon growth, development, and survival. Although data exist on aspects of the ocean and estuarine ecology of juvenile salmon in the Pacific Northwest, virtually nothing is known of salmon while in the San Francisco Estuary and the coastal ocean off central California. In fact, information derived from northerly populations often form the basis of management decisions in California. Differences in environmental conditions, genetic traits, and physiological adaptations of California stocks may require data specific to California salmon to effectively recover and manage them. Information on the biology of juvenile salmon in ocean and estuarine habitats has been identified as a high priority research need by the Pacific Fishery Management Council (Research and Data Needs 1998-2000, PFMC, September 1998) as well as the scientific community (Estuarine and Ocean Survival of Northeastern Pacific Salmon, Proceedings of the Workshop, April 1997; NMFS Estuarine and Ocean Salmon Strategic Research Plan, April 1998). Consequently, in 1995 we initiated a study of juvenile chinook salmon as they emigrate through San Francisco Estuary was initiated. This study is intended to last 10 years to provide sufficient data for assessing interannual variability and the influence of environmental variables. Early on, juvenile salmon collected incidentally during the annual May-June juvenile rockfish survey off central California revealed interesting growth and energy dynamics. This caused us to expand the study in 1998 to the Gulf of the Farallones, the coastal ocean seaward of the San Francisco Estuary.

The goal of this study is to increase knowledge and understanding of juvenile chinook salmon physiological ecology in the San Francisco Estuary and the coastal ocean. Specific objectives are to determine: (1) residence time, growth, energy dynamics, and feeding in the estuary; (2) relative abundance, distribution, growth, energy dynamics, and feeding in the ocean; (3) population structure and natal stream sources of ocean stocks; and (4) influences of environmental and oceanographic factors on growth, energy accumulation, and feeding.

Juvenile salmon are collected by trawl in the San Francisco Estuary during May and June, when fall-run juveniles, by far the most abundant stock, emigrate through the estuary. Between 1995 and 1999, four sites were sampled in two sweeps during the two-month period: at the estuary entrance (Chipps Island), after passage through Suisun Bay, at the restriction between San Pablo Bay and San Francisco Bay, and at the Golden Gate, the exit from the estuary. Since 1999, only Chipps Island and the Golden Gate have been sampled. In the coastal ocean, stations associated with oceanographic features (eddies, upwelling centers, estuary plume, jets) and along latitudinal transects on the shelf are visited three times each year: after juvenile emigration through the estuary is completed (June-July), a few months later after the "critical period" (August-October), and at the end of winter after the downwelling, or low productivity, period (February-March). At each station, salmon are collected by 264 Nordic Rope Trawl towed at the surface, and stratified plankton, neuston, and chlorophyll samples and CTD data are acquired. Fish by-catch is enumerated and a subsample of each species is measured. In the laboratory, fish are measured, weighed, and tissues are removed for further analyses. Otoliths are analyzed for age and growth, stomach contents are used to determine prey selection and feeding intensity, and fin clips are preserved for genetic analysis. Bodies are retained for protein and lipid class analyses. Otoliths from adult salmon are collected from party boats between Bodega Bay and Monterey and subjected to microstructural and microchemical analyses to determine origin (stream, hatchery/wild).

Juvenile salmon enter San Francisco Estuary at about 4.5 months old, and spend about a month transiting the estuary. They exhibit limited growth while in estuary (0-0.28 mm/d FL; -0.2 - +0.8 g/d wt), but growth increases sharply upon ocean entry (Fig. 5), and condition factor (K) declines. Energy (lipid) dynamics vary year-to-year and among locations, but in general decline in the lower estuary and upon entering the ocean as growth increases. Smoltification (gill Na^+,K^+-ATPase activity) is essentially complete when juveniles enter the estuary. Prey selection changes from insects and amphipods in the upper estuary to include larval fish in the lower estuary. Principal component analysis reveals that measures of growth and energy

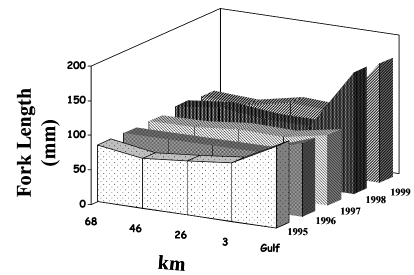


Fig. 5. Mean fork lengths of juvenile chinook salmon during May and June at locations in the San Francisco Estuary and Gulf of the Farallones between 1995 and 1999. Estuary locations denoted by distance from the Golden Gate. Within the estuary, mean fork lengths were significantly different among years, locations,

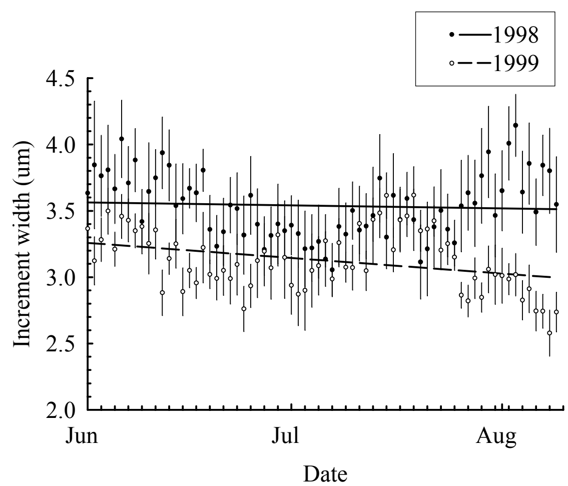


Fig. 6. Mean daily otolith increment widths for subyearling juvenile chinook salmon captured in the Gulf of the Farallones in the fall of 1998 and 1999. There was no significant difference in ages of samples between the two years. Increment widths were greater in the 1998 El Niño period than in the 1999 La Niña ($P<0.0001$). N = 10 for each year.

accumulation are positively related to residence time and zooplankton abundance. The 1999 year class was the most robust (most abundant, best growth, most stored lipid, and best condition) of those between 1995 and 1999. These results in general suggest that juvenile chinook salmon have little estuarine dependency in San Francisco Estuary, expediting emigration to the coastal ocean with its high biological productivity and increased survival potential. After ocean entry (June-August), most subyearling chinook salmon remain in the Gulf of the Farallones. A portion proceed north on the continental shelf, the northward distribution on shelf increasing as the season progresses (September-November). Highest CPUEs occur at an eddy north of the Golden Gate, and at a coastal jet south of the Golden Gate. We have no evidence of extended southward movement by subyearling fish. Growth rate and condition factor (K) increase in the ocean; feeding rate intensifies and lipid stores are depleted. Young chinook prey primarily small fish, decapod and euphausiid early life stages, and amphipods. Subyearling chinook salmon grew faster during the 1998 El Niño than the 1999 La Niña (Fig. 6). Microchemical analysis (Sr isotope ratios) of juvenile chinook otoliths from the Central Valley shows promise as a tool to determine stream of origin, and microstructural analysis allows determination of hatchery or wild origin.

Physiological Ecology of Salmonids in Small Estuaries

The importance of estuaries in salmonid early life history has been debated. Previous research has focused on large estuaries that remain open all year. Smaller estuaries, many of which are closed seasonally by sandbars, have received little study. It has been hypothesized that the smaller estuaries along the California coast are important rearing areas for steelhead and coho salmon, and that the opening or closing of the estuaries may affect the development and ultimate survival of young salmon. This project investigates salmonid utilization of some small estuaries by looking at population abundance, growth, feeding, and metabolic status of juvenile fish throughout the year while these estuaries are both open to the ocean and closed by sandbars. This initial investigation focuses on four small estuaries that range across approximately 170 miles of California's central coast (approximately 2° latitude): Redwood Creek (Marin County), Gazos Creek (San Mateo County), Scott Creek (Santa Cruz County) and Willow Creek (Monterey County). All of these creeks have established steelhead populations, and all except Willow Creek have coho salmon. Studies have shown salmonids are most abundant in the estuaries between April and October. During this time, the water quality of the estuaries may change dramatically due to increases in temperature and cessation of water outflow due to sandbar formation. In some estuaries, breaching of sandbars by humans occurs in an effort to reduce the risk of flooding adjacent lands. The effects of sandbar formation and artificial breaching on salmonid development are unknown. Increased knowledge of salmonid biology in small estuaries will contribute data necessary for effective protection of these endangered species and their habitats.

The goal of this study is to determine growth and physiological status of juvenile salmonids, and their utilization of these small estuaries across time. Specific interests include how the open/closed state (presence or absence of a sandbar blocking ocean access) of the estuary affects the fish and whether there are similar patterns within these four creeks. Specific objectives include: (1) determining population abundance and utilization of the estuaries, including residence times; (2) determining growth rates, feeding patterns and smoltification of juvenile salmonids; (3) determining environmental profiles and thermal preferences of fish in the estuaries; (4) determining patterns of resting metabolic rate across seasons and temperatures; and (5) comparing these data across the latitudinal gradient of this study and with previously published results from other estuaries.

Population abundance and estuary utilization will be determined with regularly scheduled snorkel surveys, seines, and tag recaptures. Weights and lengths are collected for each fish to ascertain growth rates. As ocean survival has been shown to be directly related to size, growth rates and size of fish upon outmigration are important parameters to monitor. Fish will be marked, either with an injectable visible latex polymer or a PIT tag so that individuals can be followed through time. Feeding patterns will be determined by collecting stomach contents of lightly anesthetized fish or from those that have been sacrificed for tissue collection. These samples will be compared with plankton, neuston, and benthos samples from the estuaries. Prey selection may be affected by intra- and interspecific competition as well as prey quality and availability. Temperature preference profiles will be determined by tagging fish with archival temperature tags and comparing these with temperature loggers placed in the streams. This may provide an idea of fish movements within the estuaries, especially during those times of the year when there is a characteristic thermal profile of the lagoon/estuary. Resting metabolic rates will be determined in small closed-flow respirometers. By comparing metabolic rate across seasons and at various temperatures, changes in energy demands can be observed. Similarities or differences found between fish from different creeks could reflect developmental differences, genetic differences, and/or environmental differences. Levels of energy demand (metabolic rate) will be compared to diet preference and any covariations will be investigated. Swimming efficiency will be measured in a swim tunnel respirometer. This will allow us to compare swimming performance between species and creeks and through time. These data will provide insight into such things as competitive ability within the lagoon, prey capture, predator avoidance, and endurance that may be important once the fish enter the ocean. Analysis of tissue (muscle, heart, liver and gill) enzymes and fuel (lipid) supplies can reveal the metabolic poise of fish that may be affected by environmental factors like developmental temperature, genetics, and state of smoltification. Fin clips will be collected for DNA extraction and genetic analysis, or archiving in salmonid tissue archives. Scales will be collected for age determination, and otoliths will be collected from all fish that are sacrificed for any experiments for confirmation of age. Environmental data at each estuary will be collected, i.e., temperature, salinity, pH, $[O_2]$, turbidity, flow and open/closed state of the estuary.

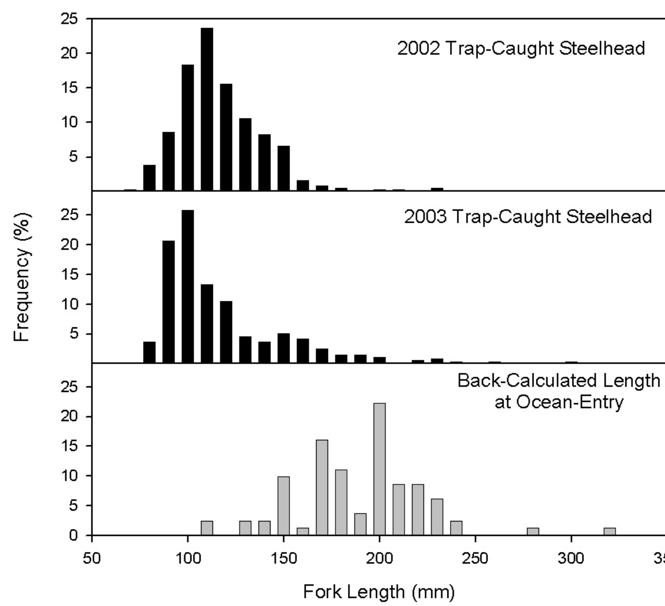


Fig. 7. Estimated fork lengths of fish at ocean entry are significantly larger than those of downstream migrants.

This study was initiated in Spring 2003, and not all components of the investigation have been implemented. Previous snorkel surveys (during 2000-2002) in these small estuaries to determine abundance of species and their life history stages within the estuaries showed the heaviest use of the estuaries occurred from April through October for both coho salmon and steelhead trout (both 1+ and YOY life history stages). In a study initiated in Scott Creek, recaptures of PIT-tagged fish, both in the lagoon and upstream, have shown significant differences in growth rates, with fish growing faster in the lagoon. Growth rates of both steelhead and coho salmon are at least twice as fast in the lagoon compared to upstream (0.55 mm/d vs. 0.20 mm/d for steelhead and 0.53 mm/d vs. 0.09 mm/d for coho salmon). Fork lengths of fish at time of ocean entry were estimated by analyzing scales of returning adults. These fork lengths were significantly larger than those of downstream migrants (caught just before entry into the estuary/lagoon) (Fig. 7), suggesting that there may be significant growth in the lagoon, and that this growth is necessary for survival at sea and the ultimate return for spawning.

Comparative Life History Studies of Wild and Hatchery Salmonids

Scott Creek and its tributaries form a coastal watershed in Santa Cruz County located within the Central California Coastal ESU and are home to both steelhead and the southernmost population of coho salmon. Both species are supplemented by a small conservation hatchery and listed as threatened under the Endangered Species Act. Research in this stream is driven by a lack of current life history data and the potential for adverse effects of artificial propagation on wild fish.

Our objectives are to: (1) investigate how Scott Creek salmonid populations are being affected by historical and current artificial propagation techniques, and (2) improve our understanding of coho salmon and steelhead life history strategies. The study began in January 2002 and consists of three main components: (1) behavioral and physiological comparisons between hatchery and wild fish during juvenile stages; (2) measurements of adult reproductive behavior and reproductive success; and (3) population genetics. Areas of study included comparative development and competitive interactions between juvenile hatchery and wild fish. Specific concerns included hatchery fish 1) preying upon or competing with smaller wild fish for in-stream food resources, and 2) influencing or stimulating wild fish to migrate downstream prematurely. The results will be used to manage these species and rebuild populations to levels that are resilient to environmental and anthropogenic influences.

Behavior and Physiology

Monitoring of downstream migrants and extensive surveys throughout the watershed indicate that the majority of hatchery fish exit the watershed within a few weeks of planting. The migration period for wild fish of both species was much longer, lasting several months and appeared not to be influenced by movements of hatchery fish. Hatchery steelhead grow faster in captivity than young-of-the-year wild stocks growing in the upper watershed, but were comparable in size at planting to wild steelhead smolts entering or residing in the estuary. Hatchery coho salmon were on an accelerated growth regime during 2002 to induce early returns of precocious fish from both sexes to rebuild a nearly extirpated year-class and were much larger than wild smolts. Measurements of gill Na^+ K^+-ATPase activity indicated that downstream migrants of both species and groups were physiologically prepared to enter seawater at the time of migration. ATPase activity levels in non-migratory wild coho salmon and steelhead remained low throughout the year, even during the period of peak downstream migration. ATPase activity declined for smolts residing in the closed freshwater lagoon during summer months, but elevated during late fall when the lagoon reopened.

Adult life history research has only addressed steelhead, due to limited numbers of coho salmon, and focused on competitive interactions between hatchery and wild fish. Adult steelhead were captured in stream by teams of divers and additional persons blocking pool exits with dip nets. Our research examined areas where hatchery practices had been reported to cause: (1) a shift in the run timing for hatchery versus wild fish; (2) artificial selection for larger size; and (3) hatchery fish out-competing wild fish for mates and breeding substrate. There was a significant difference in the return time for hatchery versus wild fish, hatchery fish being concentrated in the middle of the spawning season, whereas wild fish returns were distributed through the entire spawning season. Scales were used to assess age at ocean entry and return for hatchery and wild fish. During the juvenile stage, hatchery fish spent less time in freshwater than wild fish. No significant differences in juvenile age were observed between sexes. There was no difference between hatchery and wild fish for time spent in saltwater. However, males spent less time at sea than females. There were no significant differences observed in mean size between returning hatchery and wild fish, or between males and females. However, the variance in length differed between hatchery and wild males, with wild males having a much greater size variance.

Thirty-three spawning events were monitored for competition between hatchery and wild fish. The largest male was dominant in all cases where male competition was observed (n= 21). Hatchery and wild fish were observed to spawn with each other (n= 14). During several observations, wild male steelhead were observed competing with each other for access to females (n=4). There were no observations of hatchery and wild males competing for access to females, nor observations of hatchery males competing with each other for female access. Mature male parr were observed at many spawning events competing with steelhead males (n=11). No females were observed competing for space, however superimposition of redds was fairly common in the watershed with no specific hatchery/wild bias. The impact on egg development and emergence is unclear and probably influenced by weather and fish density. No significant differences were observed for reproductive success from preliminary measurements of hatchery versus wild fish based on microsatellite DNA analyses.

Population Genetics

Population genetic analyses were conducted with 18 microsatellite loci on 960 Scott Creek steelhead samples. All Scott Creek steelhead are more related to themselves than to other coastal steelhead populations. There are at least four subpopulations within Scott Creek: Big Creek tributary residents (above and below a falls, which is a barrier to anadromy), each of two hatchery year-classes, and wild steelhead (adult steelhead combined with young-of-the-year sampled in 2002). Small genetic differences and assignment tests confirm that resident fish above and below the anadromy barrier in Big Creek have unlimited gene flow between them (in one direction). The high degree of relatedness to Scott Creek steelhead suggests this life history trait arose from a common steelhead stock and that a potentially sympatric breeding population is being maintained. However, male "residents" (130-250mm, 2-5yrs old) below the anadromy barrier are regularly observed attempting to spawn with adult steelhead. Reproductive maturity has been observed in residents of both sexes below the falls. Gill Na^+ K^+ -ATPase activity measured in residents is always at baseline levels, supporting the distinct life history hypothesis. Hatchery populations are probably distinct due to the limited parental stock (<12 parents/generation). It is likely that the wild steelhead samples are composed of more than one subpopulation, but further analyses are required. Final calculations for F_{st}, Hardy-Weinberg equilibrium and linkage disequilibrium statistics are not yet available. Similar analyses are underway on Scott Creek Coho salmon.

Southern Coho Salmon Captive Broodstock

Coho salmon populations are declining throughout their range on the West Coast. Of six ESUs, three are listed as threatened under ESA. Southern coho salmon, populations south of the Golden Gate, are at high risk of extinction. All streams south of the Golden Gate have lost their coho salmon runs except Scott and Waddell Creeks in Santa Cruz County. In Waddell Creek, spawning runs have declined from around 250 adults in the 1930s to less than 50 today. Scott Creek, with historically similar run sizes, has had its spawning population reduced to 30-40 fish in the best years. Populations would be in even greater jeopardy without supplementation by artificial propagation. The Monterey Bay Salmon and Trout Project maintains a conservation hatchery, the Kingfisher Flat Hatchery, on a tributary of Scott Creek. Since the mid-1970s, Scott and Waddell Creeks have been stocked with progeny of coho salmon trapped in Scott Creek and spawned at the hatchery.

In recent years, the collection of broodstock has become increasingly difficult due to poor adult returns. The causes are unknown, but probably related to poor ocean survival and premature flushing of young fish from freshwater habitats by storms associated with El Niño events.

Other streams near Scott and Waddell Creeks had coho salmon runs historically but do not presently, although suitable spawning and rearing habitats are available. In 1995 the California Fish and Game Commission listed southern coho salmon as endangered under the California ESA. In 1996, a Restoration Plan for their recovery was initiated. A team of NMFS, CDFG, U.S. Fish and Wildlife Service, and academic scientists recommended a multifaceted recovery plan that included artificial propagation and reintroductions with a captive broodstock component. They also recommended research and monitoring of southern coho life history traits, genetics, ecological requirements, and population dynamics.

The goal of the captive broodstock program is to ensure the continuation and recovery of coho salmon at the southern margin of their distribution. Specific objectives are to: (1) provide gametes, which preserve and increase genetic diversity, to the Kingfisher Flat Hatchery for the continued production and enhancement of indigenous coho salmon; (2) provide mature adults for spawning in suitable streams south of the Golden Gate; and (3) increase knowledge and understanding of the physiological, ecological, and genetic attributes of southern coho salmon by use of broodstock progeny for research.

Progeny of wild coho salmon caught in Scott Creek are artificially propagated at Kingfisher Flat Hatchery. Five hundred are randomly chosen, PIT tagged, and fin clipped for genetic analysis. From the analysis of12 microsatellite loci, 150 fish with maximum genetic diversity are separated into two groups after smoltification. One group (100) is placed in a seawater facility at the NMFS Santa Cruz Laboratory and a secondary group (50) is maintained in a freshwater facility at the Kingfisher Flat Hatchery. Broodstock are fed at approximately 2% body weight per day and are evaluated periodically.

As fish approach reproductive maturation at three years of age they will be analyzed by ultrasound to determine sex and the degree of gamete development. Eggs or sperm will be stripped from ripe adults and used in a spawning matrix of wild fish. The hatchery is permitted to spawn 30 females and 45 male fish; gametes from captive broodstock will be used to supplement spawning of naturally returning salmon only if necessary.

If there are broodstock exceeding hatchery needs, they will be introduced into suitable streams south of the Golden Gate, i.e., those with no or low numbers of naturally returning coho salmon. Decisions on which streams are suitable will be with the guidance of the Central California ESU TRT.

Once the captive broodstock program has demonstrated success, we intend to use a limited number of progeny for laboratory experimentation to determine physiological and ecological performance and adaptations to environmental conditions that exist at the southern end of the distribution.

The results of the captive broodstock program will be evaluated at the hatchery and in the field. In the hatchery, fertilization rate, growth rate, and survival of young from broodstock gametes will be recorded and compared with values from hatchery-spawned wild fish. A temporary weir will be installed in Scott Creek in the fall of 2003 and will allow estimates of growth and survival of returning broodstock progeny, since they will all be fin-clipped and a subset will contain PIT tags. The captive broodstock program will run for nine years. When southern coho salmon stocks in Scott and Waddell Creeks are self-sustaining, or after three generations of each of three year-class lineages, whichever occurs first, the program will be discontinued. The first broodstock was started with the 2001-2002 year-class, the strongest of three year-class lineages in Scott Creek. They were hatched between during March 2002. One hundred and eight (108) progeny were transported to the saltwater facility at SCL and 43 were retained in a freshwater tank at Kingfisher Flat Hatchery in April 2003. To date, five of the saltwater broodstock have died; none have died at Kingfisher Flat Hatchery. No diseases have occurred.

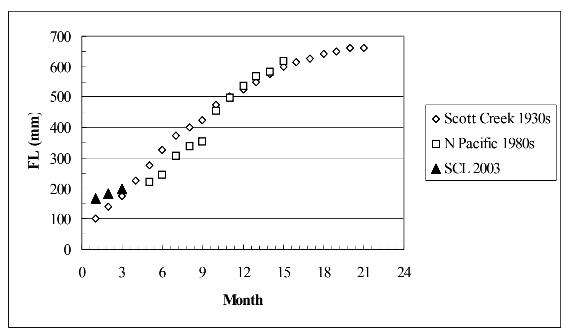


Fig. 8: Growth in fork length of Santa Cruz Lab coho salmon captive broodstock in relation to populations from Scott Creek in 1930s and North Pacific in 1980s. Month 1 is April.

Growth of broodstock is presented in Fig. 8. As of 29 July 2003, when saltwater broodstock were last evaluated:

- Age: 501 days (birth date - 15 Mar 2002)
- Mean fork length: 200.6 ± 2.8 mm
- Mean weight: 117.5 ± 8.8 g
- Mean growth rate:
  - fork length: 0.40 ± 0.05 mm/d (0.2 %/d)
  - weight: 0.77 ± 0.10 g/d (0.7 %/d)

Chinook salmon vital rates as leading indices to the impacts of ocean climate change on fishery resource productivity

The overall goal of this project is to provide information necessary to effectively adapt fishery management to mitigate the ecological, social and economic impacts of major shifts in the productivity of salmon resources of the North Pacific Ocean related to shifts in ocean climate. In the case of the salmonid resources, it is likely that impacts of ocean climate shift will be manifest first and most profoundly on California populations at the southern end of their range where environmental conditions are marginal. This project will contribute to attaining the goal by developing specific vital rates (i.e., age at maturity, survival, and growth) of several populations of chinook salmon along the west coast as indices to climate /productivity shifts. This research product will contribute to improved fishery management in general, but especially the limited, but valuable, salmon fisheries for those ESU's not listed under ESA. Just as important, these results will allow scientists and managers to better understand and predict the impacts of ocean climate shifts on extinction risk and recovery planning for those salmon ESU's listed under ESA.

This work is focused on chinook salmon, which have an extremely flexible life history, thus offering the opportunity to evaluate the effects of a changing environment on variation in life history patterns and stock productivity. Chinook salmon scales, which display a record of individual growth, are being obtained from stocks of different life-history forms (ocean and stream types) across the entire range of the species. We have begun examining the scale growth patterns on a 20 year time series of scales of fish from Redwood Creek in Northern California, and expect to receive time series of chinook salmon scale collections from collaborators in Washington and Alaska state fish and game agencies. In addition to these biological collections, environmental data, including sea-surface temperature, sea level, PDO indices, and upwelling indices have been obtained and is being processed for data analysis with the cooperation of Pacific Fisheries Environmental Laboratory and University of Washington along the feeding and spawning range of Chinook salmon for the last three decades. Ultimately, through comparison of variation in vital rates to variation in the environment and stock levels, we will develop a means to predict the influence of environmental change on vital rates and stock production.

Future Research Directions

Marine and Estuarine Habitat Use by Anadromous Fishes

Movement patterns and habitat usage are among the most important, but unresolved, aspects of fish biology. Recent advances in tagging technology of fishes allow a more comprehensive record of movement patterns through various habitats. Several anadromous species that utilize the San Francisco Bay-Delta system and coastal streams are ecologically and economically important, have substantial temporal variability in abundance, and are suitable for tagging. Chinook salmon, coho salmon, and steelhead have been greatly depleted; all central California species are listed or candidates for listing by the ESA. Green sturgeon has been petitioned for listing and a recent biological review noted the paucity of data to fully evaluate the status of the species. Striped bass, although not under ESA consideration, has shown large variations in abundance the causes of which are unknown but have been hypothesized to relate to the extent of ocean entry.

The objective of this project would be to determine movement patterns of salmonids, green sturgeon, and striped bass in the San Francisco Bay-Delta ecosystem, coastal streams and ocean of central California. A combination of acoustic and archival tags will be employed to monitor movement through estuaries and into the coastal ocean. A system of acoustic receivers (nodes) will be placed at the mouths of selected estuaries, including San

Francisco Bay, and along transects across the continental shelf. Other nodes will be placed at locations within the watersheds to track movement patterns prior to ocean entry. Data stored in nodes will be collected by retrieving nodes using acoustic releases. Developing technology will allow data retrieval by towing a modem near the nodes in the near future.

Yearling chinook salmon, coho salmon, and steelhead, sturgeon, and striped bass will be implanted with acoustic tags. Another subset of each species will be fitted with archival tags. These tags will record temperature; temperature, salinity, and depth; or temperature, depth and geoposition, for up to three years. Choice of tag type depends on species, size of animal, and cost. Retrieval of archival tags will require capture of the fish. Extensive monitoring programs by several state and federal resource agencies, and fishing, in San Francisco Estuary and coastal streams should improve tag recovery.

Data from tags will be compared with environmental gradients to estimate location. Acoustic data will provide times of passage at node locations. The data will be used to determine movement direction and rate, and habitat usage, e.g., estuarine residence, migration rate, thermal habitat, and diel depth preference.

Comparative Life History Studies of Wild and Hatchery Salmonids

The results from the first several seasons of research in Scott Creek have proven the site to be a powerful research laboratory for both management and basic research questions. As a result, several projects are underway which will provide valuable data on hatchery/wild reproductive behavior/success, critical habitat assessment, ocean movements/habitat preferences and escapement measurements. Central to these studies will be the installation of a passive resistance-board weir to capture and sample most returning adults of both species.

Reproductive Behavior/Success

Precise measurements of reproductive success will be made possible by near-complete sampling of the small closed breeding populations of coho salmon and steelhead (estimated 400-800 returning adults/species) and in-house capacity to process a large number of microsatellite markers for this volume of samples. Specific questions to be addressed include differences between hatchery and wild fish as well as relative reproductive success measures for different life history strategies including early returning and full grown adults (coho salmon and steelhead), repeat spawners (steelhead) and resident trout. These data will be used with a growing video library of in-stream spawning behavior to determine which behaviors are important contributors to reproductive success.

Escapement

Total escapement measures will be made possible by accurate counts of returning adults. All fish passing through the weir will have an external Floy tag attached for identification during subsequent spawner surveys. Ratios of tagged to untagged fish observed during these surveys will be used to calculate the number of fish evading the trap on their way upstream. Approximately 500 fish from each of the four groups–hatchery/wild, coho salmon/steelhead–were PIT tagged as smolts during spring 2003 downstream migration to measure ocean survival rates for each group. Proportions of tagged to untagged returning adults will be used to estimate the total number of smolts that departed the watershed in 2003.

Importance of the estuary

Scale samples of returning adults are being used to back-calculate smolt size at ocean entry. These sizes are significantly greater than typical sizes observed entering the estuary. Currently there is a gap in our knowledge of estuarine residence time and growth. Return data on fish, PIT tagged and measured as smolts, will help calibrate back-calculated size estimates, determine critical size thresholds for ocean survival, and define how important the estuary is for smolt growth. In-stream PIT tag readers will be placed at the head of the estuary to measure time of downstream migration and estuarine entrance for fish that were tagged upstream as parr.

Ocean Habitat Use

We have begun implanting smolts with temperature loggers to collect data during the oceanic life-cycle phase. These data will be used to assess large-scale movements relative to sea surface temperature, individual variability, and temperature-growth relationships. During spring/summer 2003, 100 hatchery steelhead, four wild steelhead, and 27 hatchery coho salmon were released with temperature logger tags. Several fish have been recaptured in the estuary, having not yet departed for sea and appear to be completely healed from their surgeries. Tags will be recovered from the fish returning as adults through the weir in 2004 and 2005. We plan to attach external time-depth-temperature-geolocation-tags to adult female steelhead kelts as they return to sea during the spring of 2004.

Climate Change Effects on Central California Salmonids

Chinook salmon from California's Central Valley and coho salmon populations from central California coastal streams are at the southern end of their distributions. Steelhead, although distributed farther south, experience aquatic habitats in central California often subjected to high temperatures and low stream flows. Climatic warming is likely to exert its influence on streams in central California before more northerly systems. Effects will include increasing water temperature and altered hydrographic flows and patterns, which may affect the growth, development, and survival of salmon.

The objective of this study will be to estimate the consequences of climatic warming on central California salmonids. Using data generated since 1995 on the physiological ecology of juvenile chinook salmon, data from the small estuary study on growth and metabolic rates of juvenile steelhead and coho salmon, and a combination of process-oriented laboratory and field studies, the effects of elevated stream and ocean temperatures and altered freshwater flow patterns will be modeled to elucidate possible effects of climatic warming on growth, development and survival.

Molecular Ecology Team

Introduction

The Molecular Ecology Team uses molecular and population genetic methods to study questions in ecology, evolution, conservation and management of marine biological systems in California. Most of this work involves salmonids, and is in collaboration with other teams in the SCL.

Research Activities

Population genetic structure of California Anadromous Salmonids

We are collecting multilocus microsatellite genotypes to study population structure of steelhead, chinook and coho salmon in the coastal and inland rivers of California. We are examining the magnitude and distribution of population genetic variation at multiple geographic levels, including stream reaches within a river, different tributaries of larger river systems, different rivers and, finally, different ESUs.

In steelhead trout, population structure has been investigated using data from 18 microsatellite loci and samples collected from over 60 sites covering almost the entire range of the species in coastal California. The novelty of this work is that the samples consist entirely of individuals from the same year class, which were sampled the same year, using a standardized stream sampling protocol. This sampling was coordinated by the Salmon Population Analysis Team.

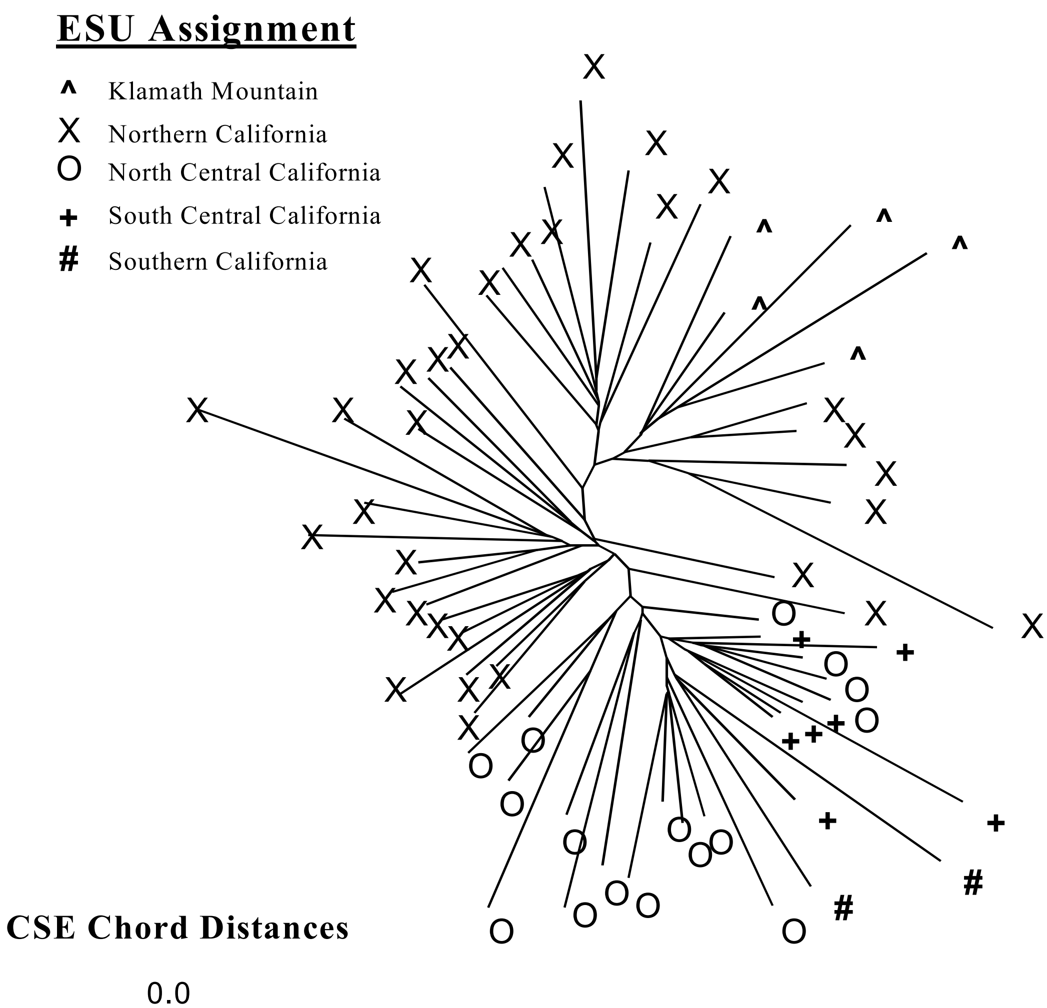


Fig. 9: Phylogeographic tree of 61 steelhead populations from coastal California. Data used in tree construction consist of a mean of 18 microsatellite genes assayed in a mean of 66 individuals per population. Tree was constructed using the Cavalli-Sforza and Edwards (CSE) chord distance and the neighbor-joining alogrithm.

This work has revealed a high degree of genetic differentiation between steelhead populations (Figure 9), which provides the ability to use these genetic data to assign individuals to river system with greater than 80% accuracy. In many cases, this level of accuracy was achieved even between different tributaries of the same river. We are currently in the process of extending this work to include populations from the Central Valley, and to include denser sampling in the southern California ESU. We are also starting an assessment of temporal stability in genetic composition and of ancestry for resident rainbow trout populations upstream from barriers to anadromy.

We are also examining the genealogical relationships of alternative life history forms to the dominant, anadromous form in several rivers. Preliminary investigations have revealed that the "summer" steelhead form in the Eel River and the "resident" form in Scott Creek. are recently derived from the anadromous stock in the same river. This work is also examining reproductive interactions between these forms, but results are not yet available. Finally, we are examining how population genetic composition changes in Scott Creek. from the beginning to the end of a bout of outmigration by assaying individuals in a downstream migrant trap. This work is collaborative with the Salmon Ocean and Estuarine Ecology Team.

With coho salmon, we are currently completing a phylogeographic study of populations in the central California ESU, which ranges from the Eel River to Scott Creek, north of Santa Cruz. This work is using 18 microsatellite genes to determine population structure, identify appropriate streams for use in captive broodstock and reintroduction programs and to determine the source of colonists for a newly occupied stream (Pine Gulch Creek.) in Marin County. Preliminary analyses of a 12 gene dataset have revealed extraordinarily deep divergences between adjacent streams, and have identified the source of colonists with great confidence. These preliminary data have also been used to guide broodstock collection for a captive rearing program in the Russian River, where coho salmon have been nearly extirpated.

We are currently starting a large-scale phylogeographic analysis of chinook salmon in California. Previous work has revealed several components of population structure in the Central Valley (three genetically distinct groups; fall, winter and spring runs). Our work is expanding the coverage in the Central Valley to include all extant runs of chinook salmon and tripling the amount data brought to bear on questions of population structure. We are also extending the work to include coastal California populations of chinook salmon.

The chinook salmon population structure project is also being integrated with that of 6 other labs in Oregon, Washington, Canada and Alaska to create a coastwide dataset for use in genetic stock identification and mixed stock analysis of the chinook ocean fisheries. This collaborative effort is just beginning, and the SCL is taking the lead in providing the electronic framework for data integration and reporting. We have also instigated a change in the physical standards used in data calibration and integration, which is resulting in a shift to a standard set of families, from a previously implemented locus-specific set of allele nomenclature tools.

Population Genetics - Analytical Methods

Many analytical methods in population genetics require accurate estimates of parameter values for mutation and other evolutionary forces. We are estimating mutation rates and other mutation parameters in steelhead trout and coho salmon. We are performing genotypic analysis of 18 microsatellite genes for ~5000 parent offspring pairs per species from Scott

Creek. These are the same genes being used in studies of population structure. These estimates will greatly increase the accuracy of our population genetic analyses. We are also working on the development of novel methods for detecting changes in effective size and loss of population genetic diversity using single samples in time. These methods are being applied to salmonid populations to better understand population genetic history and structure. We are also developing novel methodology for the analysis of kin relationships with molecular markers. These will be applied to the study of reproductive success in trout and to estimate heritability of variable traits.

Gene Structure of Anadromous Salmonids

We are describing gene structure for functional genes in steelhead trout. The objectives of this work are to describe position and size of introns and exons, identify polymorphic sites and design assays for surveying this variation. Using published cDNA sequences from chinook salmon and rainbow trout, we have investigated insulin–like growth factor (IGF) and heat shock protein (HSP) genes in steelhead trout. Complete gene structure has been described for one IGF gene and one HSP gene, with partial gene structure completed for another IGF and HSP gene. Work is also beginning on creatine kinase and several dehydrogenase genes. Once gene structure has been described and polymorphism identified, we will use variation in these functional genes to examine performance in the description of population genetic structure and to detect selection.

Development of Breeding Protocols for Conservation Hatcheries

We are working closely with two hatchery-based captive broodstock/reintroduction programs for coho salmon in central California, one based in Santa Cruz county (run by the Salmon Ecology Team), the other on the Russian River. We are using molecular genetic data to identify populations appropriate for use in these programs through phylogeographic analyses. We are also using microsatellite genes to help identify specific individuals for retention in the programs, through the use of methods that replicate population allele frequencies in the captive sample. We have also determined relatedness of all individuals in the captive programs to avoid inbreeding and outbreeding in breeding matrices, maximize effective population size and to guide potential reintroduction efforts. Conservation hatchery recommendations are resulting from this work.

Development of Molecular Methods to Trophic Ecology

We are developing novel methods for the study of trophic ecology. These methods focus on the recovery of prey genetic material in fecal matter and in stomach contents. They are currently being tested in Monterey Bay sea lion and harbor seals to provide estimates for impacts of pinniped predation on salmonid and other important fishery species. We have successfully demonstrated recovery of salmonid DNA from sea lion scat. In collaboration with Moss Landing Marine Lab and the Marine Mammal Center, we are conducting captive feeding experiments with both sea lions and harbor seals to assess consistency of results.

Future Research Directions

Future research in the Molecular Ecology Team will continue to emphasize collaboration with other SCL teams. In the near future, we will work with the Salmon Population Analysis Team to provide a comprehensive picture of genetic population structure in the Southern

Oregon/Northern California coho salmon ESU and to elucidate population structure of steelhead trout in the Klamath River system. The Klamath River work will be coupled with analyses of otolith micro-chemistry to examine the relationship between genealogical structure and migratory behavior. In another collaborative effort involving Sonoma State University, we will analyze samples being collected in the southern California steelhead ESU to determine ancestry of trout behind recent man-made barriers.

Much of the future work in the Team will involve the use of newly available genomics tools such as gene maps and gene expression micro-arrays. First, we intend to confirm linkage relationships in maps being constructed in other laboratories for California steelhead trout and chinook salmon populations. We will supplement these maps as necessary and then use these tools to map genes involved in traits such as age at maturity, growth rate, disease resistance and various aspects of migratory behavior in both species.

Expression arrays will be used to identify specific genes involved in these traits and to describe the biochemical basis of ecological, behavioral and physiological variation. Of great interest will be the investigation of whether similar life history variants (i.e., temporal runs) use similar biochemical mechanisms to solve similar ecological problems. To this end, we are developing a collaborative effort with Humboldt State University and UC Santa Cruz to develop a research breeding program for chinook salmon, and possibly steelhead trout, in the Central Valley to estimate heritability and study inheritance of age at maturation, migratory and domestication-related behaviors.

We also intend to extend the trophic ecology work to identify habitat components important for juvenile salmon growth through analysis of juvenile salmonids and correlation with dietary components. These methods may also be used to identify bioaccumulation pathways for environmental contaminants.

Finally, we expect to greatly expand our efforts in statistical genetic methodology with the arrival in the fall of a new scientist, Dr. Eric Anderson, who is an expert in likelihood and bayesian statistical methods. Topics to be investigated include the refinement of traditional population genetic methods to better reflect salmonid life history, the development of optimization models to minimize selection in hatcheries and the use of bayesian prior probabilities in phylogeographic analyses.

Pacific Fisheries Environmental Laboratory

Introduction

Salmon research is an important element of ongoing work at the NMFS Southwest Fisheries Science Center Pacific Fisheries Environmental Laboratory (PFEL) to understand how oceanographic conditions influence the production of fisheries resources. The research effort is rooted in the recognition that salmon are valued by a variety of stakeholders and that salmon management is a priority issue within the NMFS. Although these stakeholders often have different opinions about how the resource should be managed, there is general agreement that sustainability of salmon production is crucial. Maintaining sustainable salmon populations is complicated and challenging, in large part because of limited understanding about the impacts that oceanographic variability has on the marine life stages of these fishes. The ultimate objectives of PFEL salmon research are 1) to understand how salmon production is influenced by environmental variability and 2) to improve the scientific advice that may be used by salmon managers by explicitly accounting for environmental variability . The goals of the research are consistent with multiple objectives of the NMFS Strategic Plan for Fisheries Research[1] (SPFR).

Salmon research at the PFEL is collaborative, and expertise is contributed from NMFS scientists, scientists on contract to the PFEL, and marine scientists from numerous other agencies, academic institutions, and private organizations. Within the PFEL, four biologists are core members of the "salmon team" (*curricula vitae* provided), and these biologists work closely with other PFEL staff, particularly S. Bograd, L. DeWitt, F. Schwing, C. Wilson, and the NOAA West Coast CoastWatch manager, D. Foley. These PFEL scientists contribute to salmon research by collaborating with the biologists to access, summarize, and interpret vast amounts of *in-situ* and satellite-derived data describing environmental conditions that may influence salmon production. Collaborators external to the PFEL include researchers from academic institutions, researchers from the U.S. Fish and Wildlife Service (USFWS), commercial and recreational fishermen, and personnel from fishery-enhancement facilities. The PFEL's core "salmon team" is affiliated with the Center for Stock Assessment Research, a cooperative program between the University of California, Santa Cruz, and the Santa Cruz Laboratory (http://www.soe.ucsc.edu/~msmangel/CSTAR.html). New collaborations are also being developed with researchers at Humboldt State University to study environmental effects on reproductive investments by female Chinook salmon and researchers at Simon Fraser University to study environmental effects on the survival of chum, sockeye, and pink salmons. A large number of collaborations are generated through the PFEL's ongoing tagging studies (see *Habitat-Utilization Studies* below). Personnel from the USFWS tag fish, and the PFEL partners with commercial and recreational fishermen who provide fishing expertise and vessels chartered from multiple ports in northern California. Personnel at Rowdy Creek Fish Hatchery (Smith River, CA) assist in rearing and tagging smolts, and a similar relationship is being developed with the Central Coast Salmon Enhancement Project (San Luis Obispo, CA).

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[1] NMFS. 2001. NMFS strategic plan for fisheries research. U.S. Dep. Commerce, NOAA, Natl. Mar. Fish. Serv., Silver Spring, MD, 87 pp. Objective 1.1 of the SPFR calls for the NMFS to "periodically assess stocks to ascertain whether changes in their status due to natural or human-related causes have occurred…;" Objective 1.2 calls for the NMFS to "use stock assessments to predict future trends in stock status", taking into account "projected biological productivity" and "climatic information;" Objective 1.14 calls for the NMFS to "incorporate assessments or indices of climate variability into stock assessments;" and Objective 1.15 calls for the NMFS to "monitor climate change on inter-annual, decadal, and centennial scales and its impact on currently sustainable fisheries."

Salmon research at the PFEL is integrated through three program areas: habitat-utilization studies, correlative modeling, and population-dynamics modeling (Figure 1). Work in these three areas is concurrent, and results from the first two areas are ultimately intended to be used for developing population-dynamics models that can be used to refine expectations about the ways in which salmon populations might respond to climate variability. The development of population-dynamics models for salmon is a relatively new topic of research at the PFEL. Details about ongoing work in the three program areas are given in the following sections.

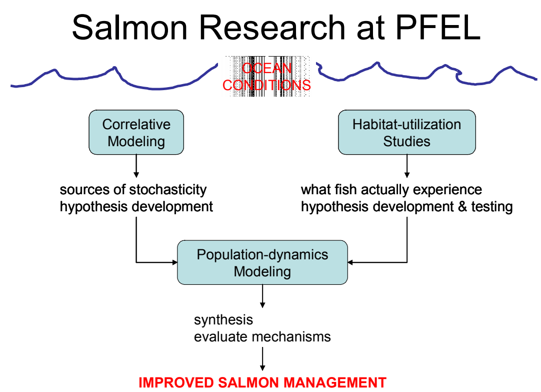


Figure 1: Program areas for salmon research at the PFEL. Our emphasis is to identify and understand oceanographic effects on salmon production. Although unique results are produced from each program area, population-dynamics models will provide a synthesis.

In response to collaborator and stakeholder interests in having quick and easy access to data and results from the PFEL's salmon research program, a website (http://las.pfeg.noaa.gov:8080/las_salmon/servlets/dataset) has been developed to host archival-tag data on a Live Access Server (Figure 2).

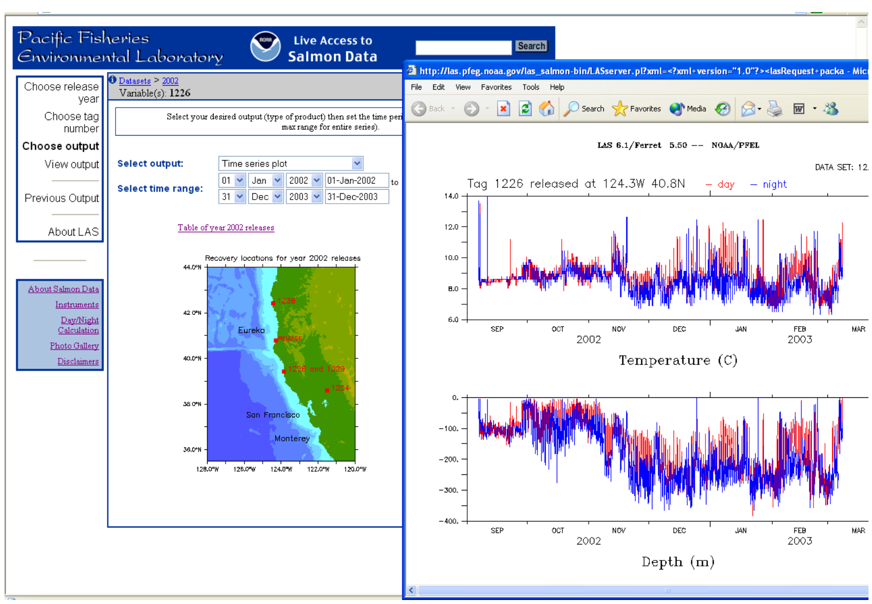


Figure 2: Screenshot of the Live Access Server that provides opportunities to visualize and download the PFEL's archival-tag data for Chinook salmon.

Research Activities

Habitat-Utilization Studies

It is increasingly understood that both freshwater and marine habitats are critical to the maintenance of healthy salmon populations. Nevertheless, despite over 100 years of salmonid research and management, knowledge about habitat use in the ocean remains poorly developed. Recognition of the importance of marine habitats has fostered new research aimed at identifying the ocean environments that salmon actually experience. Such research is important because most studies relating ocean conditions to salmon production are largely inferential; workers have generally been limited to describing environmental conditions at times and places where salmon are expected to occur. Although the latter approach has been successful, identifying the environments actually experienced by salmon will provide additional insight on how variable ocean conditions influence salmon production. This new research relies heavily on the use of archival tags.

The objective of the habitat studies is to better characterize the marine environments used by salmon. The research is intended to refine definitions of essential fish habitat for salmon and provide an improved basis for developing salmon-relevant indices of ocean condition that can be generated from physical observations. This will couple habitat-use data with correlative studies relating historical ocean conditions to salmon growth, maturation, survival, etc. This coupling will help generate hypotheses of how variability in the ocean may have affected salmon populations in the past. Ultimately, such hypotheses will lead to predictions of how salmon populations may be influenced by future environmental conditions.

Archival tags (www.lotek.com) are being used to identify the environments experienced by salmon. These tags are being used to record the time-specific temperatures and depths that maturing Chinook salmon experience in the coastal waters of California. In September 2002, the Pacific Coast Federation of Fishermen's Associations (PCFFA) was contracted to conduct tagging operations onboard commercial and sport-charter fishing vessels, forming an effective partnership with industry and sport fishermen to conduct basic fisheries research. Startup funds for this contract were obtained from a Saltonstall-Kennedy Grant. As of 11 August 2003, over 150 fish have been fitted with archival tags and released as part of this collaborative effort (Table 1). Recovery rates have been as high as 20%, and there is a high likelihood of recovering more tags in 2003 than have been recovered in any previous year. Fish have been recaptured by commercial and sport fishermen, and a reward ($100) is paid for recovered tags. The data that have been downloaded from recovered tags provide information on within- and between-year variation in habitat use by individual salmon from diverse stocks that range from the Sacramento River to the Rogue River.

Table 1: Release and recapture information from PFEL's collaborative tagging study. All fish are Chinook salmon. * Numbers as of 11 August 2003, tagging operations are ongoing and most recoveries occur in autumn

Year	Fish released	Fish recaptured from releases
2000	25	5
2001	31	2
2002	30	5
2003	70*	1*

Cluster-analysis techniques are used to analyze the archival-tag data. This approach identifies groupings of data that are interpreted as the distinct habitats used by Chinook during their ocean residence. Marine habitat use is compared across years and seasons.

Five returns from tagging efforts in 2000 and four from 2002 provided information on inter-annual variation in autumn habitat use by Chinook. The clustering analyses identified four habitats used by all fish from both years. Autumn habitats were distinguished primarily by depth and the time of day that those depths were occupied. Shallow habitats were defined by surface observations centered on 10m (inter-quartile range, IQR, ≈ 5-25m) and were split by day-time and night-time use. The deep habitat centered on 50m (IQR ≈ 40-60m), and the deepest habitat centered on 100m (IQR ≈ 70-120m). In autumn, the use of neither deep habitat was associated with time of day. Fish tagged during 2002 used slightly deeper depths than fish tagged during 2000, but this difference did not affect the habitat definitions. The ranges of temperatures that fish encountered in each habitat were relatively narrow (IQR for both shallow habitats ≈ 9.5-12.5 ºC; IQR for both deep habitats ≈ 9-10 ºC). There was relatively little interannual variation in the amounts of time that fish spent in each of these four habitats, and, during autumn, Chinook appeared to spend more time in shallow water than deep water (Figure 3). A draft manuscript describing patterns of autumn habitat use by Chinook is being prepared, and this manuscript is expected to be ready for internal review prior to the Program Review.

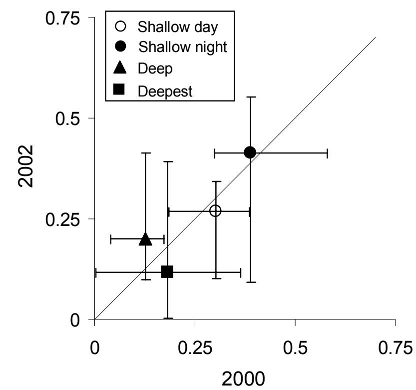


Figure 3: Weighted mean proportions (symbols) and ranges (lines) of time spent in each habitat by Chinook tagged in 2000 and 2002. The presentation is for autumn habitat use only. The 1:1 line is drawn to facilitate between-year comparison.

In 2003, two tags attached to fish that wintered at sea were recovered, providing the first, long-term glimpse into patterns of seasonal habitat use by Chinook. Figure 4 displays the time series of depth observations from one individual, but the basic pattern was the same for both. Autumn habitat use appeared to be surface oriented (see the previous paragraph), but winter habitat use was characterized by a preference for deep water. Ascents to the surface were rare during the winter. Diel patterns of habitat use also appear to be more prominent in the winter than in autumn. In the winter, the fish were consistently shallower during the day and deeper during the night. In autumn, this pattern of diel behavior held on some days and was reversed on others. During spring, the fish again showed a surface orientation, but, when compared to autumn, a much wider range of depths were used on a daily basis. A second manuscript describing seasonal variation in marine habitat use by Chinook is currently being prepared.

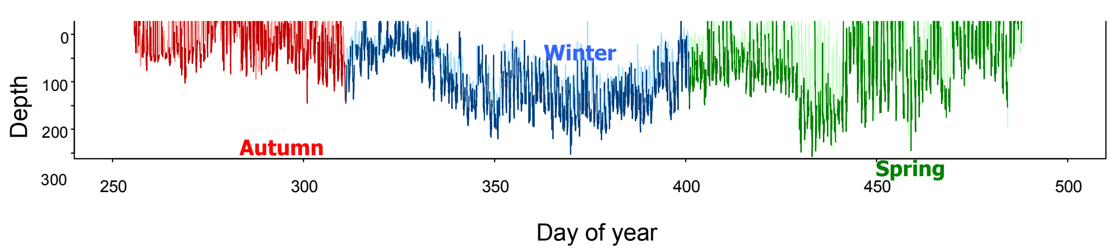


Figure 4: Seasonal depth use with diel behavior superimposed. This Chinook was released near Eureka, CA, and recaptured at sea near Fr. Bragg, CA. Red is autumn, blue is winter, green is spring. Nighttime records are colored in darker shades.

Habitat-utilization studies will be extended by leveraging results from the collaborative fish electronic tagging efforts to develop understanding in general of the inter-annual and seasonal variations in habitat use described above. There is particular interest in further describing habitat use during spring and early summer, and current tagging efforts may provide that information. In addition, there is benefit in exploring stock-specific habitat use. The initial work suggests that the habitats described by the clustering analyses are common to multiple stocks that range from central California to central Oregon. Future returns from different stocks, identified loosely by recapture location, may help to identify whether different stocks use the ocean differently. Alternatively, future returns may indicate that a single definition of ocean habitats suffices for characterizing habitat use by multiple stocks of Chinook.

Plans to combine satellite-derived sea surface temperatures, ocean-color measurements, and archival-tag data for producing maps of essential fish habitat (EFH) are also being pursued. An example of this approach is provided in Figure 5. This example is for a single fish, but efforts are underway to develop maps that allow comparisons of EFH between individuals, seasons, years, and stocks. It may be possible to develop maps of EFH in a Bayesian framework, where density functions like those illustrated in Figure 5C can be converted to probabilities by integrating over space and updated with prior information on swimming speeds and directions. Sub-surface temperature data will likely be necessary to map salmon habitat during winter because Chinook rarely come to the surface during this time (Figure 4). The possibility of producing such maps of EFH for multiple years is intriguing and may provide valuable information on habitat expansions or contractions caused by changing ocean conditions.

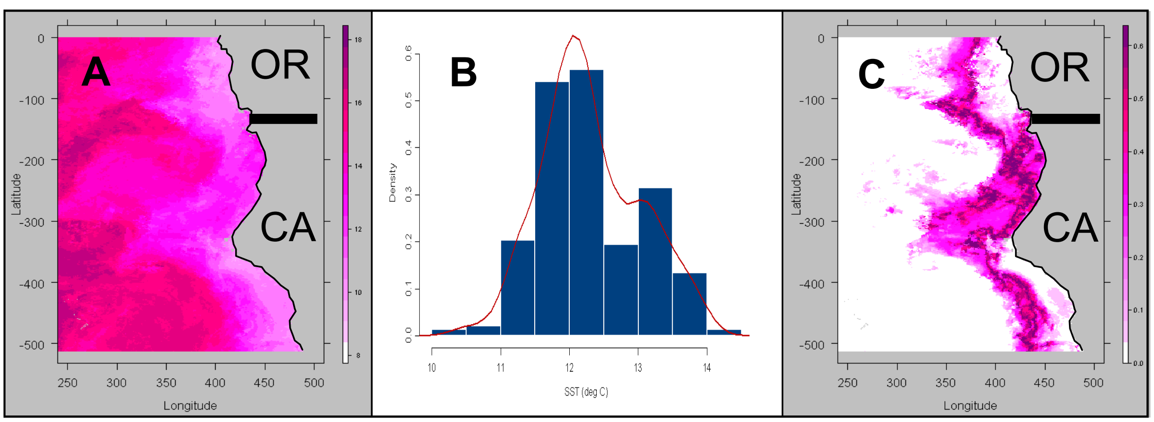


Figure 5: A) Satellite measurements of sea surface temperature off the west coast of Oregon and California during August 2000. B) Sea-surface temperature density function estimated from archival-tag data recorded by a Chinook that was at liberty during August 2000. C) Combination of sea surface temperatures and surface observations from the tagged Chinnok. Suitable surface habitats are restricted to a narrow band just off shore.

Correlative Modeling

The PFEL has completed a substantial amount of work describing how variation in survival rates of coho salmon can be attributed to variations in ocean conditions (see references to Cole (2000), Hobday and Boehlert (2001), and Koslow et al. (2001) in the attached list of publications). Work is currently under way to extend this research by considering how the marine environment influences other population-dynamics processes in salmonids. A study was initiated on how oceanographic conditions affect the age at which salmon mature. Age at maturity is important because of its significance in sexual selection, gene flow among brood years, life-history strategy, impact on harvest efficiency, and its potential use as a tool for forecasting future returns to freshwater. The proportion of coho from any given cohort that mature early is known to be related to the size of the fish at ocean entry and the timing of outmigration. It is not unreasonable to suggest that oceanographic conditions experienced during the first few months at sea would also affect the proportion of fish that mature early. Upwelling and water transport are associated with primary productivity and the movement of different organisms on and off shore, and variation in such physical processes may be associated with differences in the types and amounts of food that are available to juvenile coho. Food availability may, in turn, influence the ability of fish to pass some developmental threshold that determines age at maturity.

The objectives of the correlative modeling work are to identify those population-dynamics processes that are influenced by conditions in the marine environment and build reasonable hypotheses for developing population-dynamics models. The term "correlative modeling" is used to loosely define a suite of statistical models that can identify sources of variation in population-dynamics processes but do not identify the mechanisms by which environmental effects may be promulgated. Correlative modeling requires the development of environmental indices that appropriately describe oceanographic conditions, and initially, the development of such indices has been a primary focus in this program area.

The correlative modeling work currently depends on two main databases. Oceanographic data products developed from wind observations are used to create environmental indices, and coded-wire tag data are used to provide observations on the ages at which coho salmon mature. The oceanographic data products are accessed from the PFEL's Live Access Server (http://las.pfeg.noaa.gov/las/) and cover the years 1973 to 1997 over an area ranging from northern California to southeast Alaska (with a maximum spatial resolution of 1º x 1º). The Regional Mark Information System (http://www.rmis.org.) is queried to obtain the coded-wire tag data, and we are currently developing software to prepare these data for analysis (*e.g.*, to compute the stock-specific fraction of each brood year's production that return as 2- and 3-year olds).

Three environmental indices were developed from ocean wind products: 1) "cumulative upwelling index", 2) "local transport index", and 3) "broad transport index". A "cumulative upwelling index" was developed for each of 14 "ocean entry points" where smolts enter the ocean and are separated by a minimum of 1º of latitude. This index was produced by acumulating mean upwelling indices over the four months surrounding the peak times at which coho smolts outmigrate. The "local transport index" and the "broad transport index" were developed using output from the OSCURS model (*see the PFEL and Alaska Fisheries Science Center websites for more information on OSCURS*). The "local transport index" is used to describe the interannual variation of the source of water advected to each ocean entry point. Whereas the "broad transport index" describes interannual variation in large scale patterns of the meridional and zonal transport of surface water. OSCURS was used to simulate the trajectories of 216 parcels of surface water seeded onto a 1º x 1º grid covering the area from 40ºN to 55ºN and from the coastline to 140ºW. The simulations described the transport of these parcels during 1 February – 30 June of each year. For the local transport index, the trajectories were traced backwards for 30 days from the month of peak outmigration and their points of entry into the one degree squares surrounding each ocean entry point. Weighted centers of mass for water being advected to each ocean entry point were estimated from these 30-day trajectories. The angle and distance from each center of mass to its corresponding ocean entry point was computed, and the local transport indices are the products of these distances and the sines of these angles. Examples of plots used to develop the local transport index are provided in Figure 6. A time series of local transport indices was created for each ocean entry point, but, for the broad transport index, a single time series that applies to all ocean entry points was created. For each year and line of longitude in the initial OSCURS grid, the median latitude of the simulated end points was subtracted from the median latitude of the start points. The broad

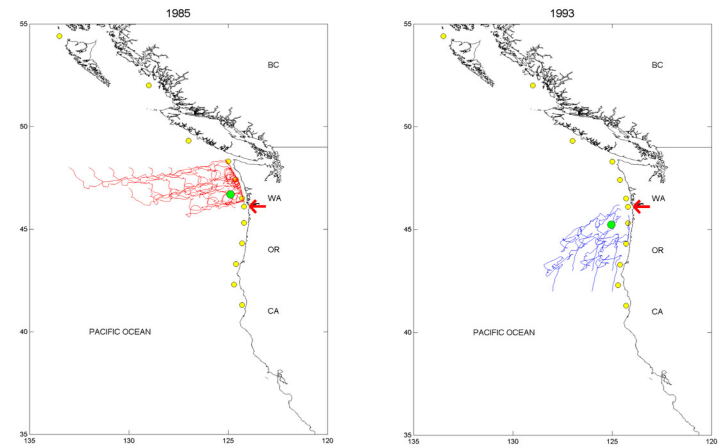


Figure 6: Visualizations illustrating the development of the local transport index. The 14 ocean entry points are displayed as filled yellow dots, and the ocean entry point for which the index is being generated (in this case the Columbia River) is identified by the red arrow. OSCURS trajectories are illustrated as lines. Red lines indicate trajectories whose end points are south of their start points, and blue lines indicate trajectories whose end points are north of their start points. The weighted center of mass for water parcels being advected to the ocean entry point during the 30 days prior to peak outmigration are identified by the filled green dots. Many ocean entry points have centers of mass that exhibit substantial variation in both the distance and angle of the center of mass and the corresponding ocean entry point.

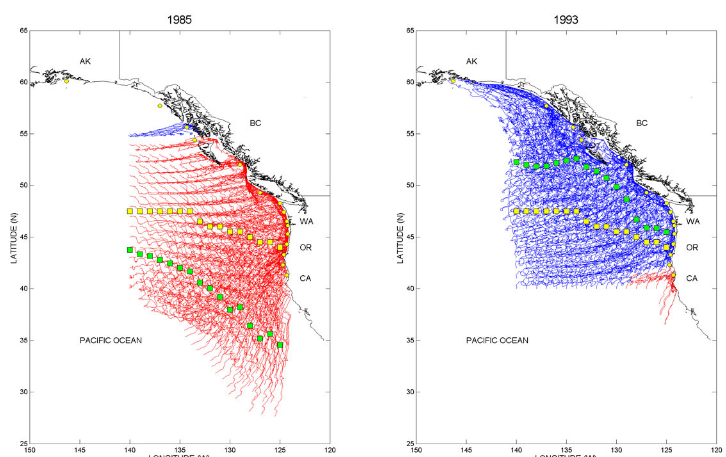


Figure 7: Visualizations illustrating the development of the broad transport index. The 14 ocean entry points are displayed as filled yellow dots. OSCURS trajectories are illustrated as lines. Red lines indicate trajectories whose end points are south of their start points, and blue lines indicate trajectories whose end points are north of their start points. The filled yellow squares indicate the median latitude of all start points for a specific line of longitude. The filled green squares indicate the median latitude of all end points for a specific line of longitude. The broad transport index is the sum (across lines of longitude) of the difference in these medians. In the panel for 1985, meridional transport is mostly from north to south and the broad transport index has a positive sign. In the panel for 1993, meridional transport is mostly from

transport index was computed by cumulating these differences across lines of longitude within each year. Examples of plots used to develop the broad transport index are provided in Figure 7. Both the development of these indices and the results were presented at two scientific meetings. There appears to be substantial interest in this work.

The three indices of ocean condition (cumulated upwelling at 14 ocean entry points, local transport at 14 ocean entry points, and broad transport) are highly correlated, and, therefore, a principal components analysis is now being used to develop a synthetic and orthogonal set of new indices. These orthogonal indices will be used to explain variation in age at maturity. Five principle components account for 80% of the covariation in the wind-driven indices of ocean condition. These principal components (PCs) have tentatively been identified as 1) the "strength of meridional transport" (PC1), 2) the "coupling of concomitant upwelling in southern areas and downwelling in northern areas" (PC2), 3) the "relative timing of the annual pulse in upwelling" (PC3), 4) the "strength of zonal transport" (PC4), and 5) the "strength of the gradient described by the transition from the California Current to the Alaska Current" (PC5). There is substantial interannual variation in the scores of all five principal components, but the first three also appear to have undergone variation over longer time scales (Figure 8). The trend in PC1 appears to indicate an increase in equatorward transport during 1973-1997; the U-shaped pattern in PC2 appears to indicate recent and concomitant increases in the amount of upwelling in the California Current and downwelling in the Alaska Current; and the shifts in PC3 appear to indicate shifts in the annual pulse of upwelling. These results are new, and have not been presented to researchers outside of the PFEL.

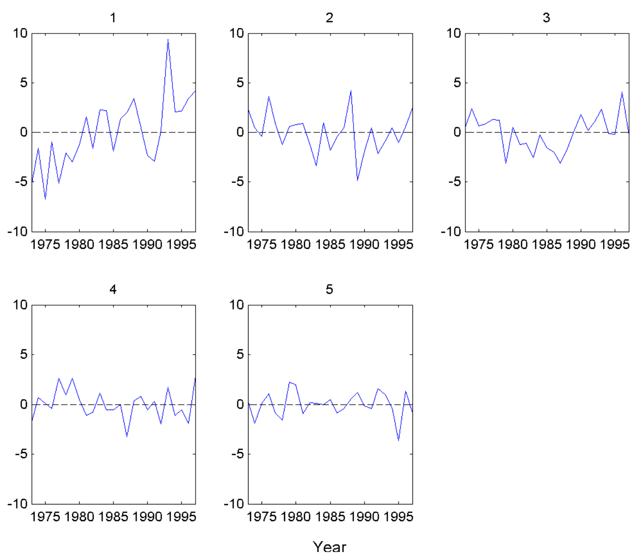


Figure 8: Time series of principal components scores explaining 80% of the covariation in our preliminary indices of ocean condition. The principal components are identified by the number displayed above each panel. Our tentative interpretation of each principal component is provided in the text.

The coded-wire tag data will soon be prepared for analysis to investigate the degree to which variation in the fractions of coho that mature early (computed for individual cohorts) can be explained by variation in the orthogonal indices of oceanographic condition developed from the principal components analysis. Mixed-effects models will be used in an attempt to capitalize on the hierarchical structure of the coded-wire tag data. The coded-wire tag data are being summarized in a way that preserves the hierarchy of river within drainage basin within ocean entry point. This hierarchy is an especially valuable component of the coded-wire tag data because release groups are also identified by stock and fish from the same stock have been released in multiple rivers, drainage basins, and ocean entry points. Thus, the coded-wire tag data, provide a unique opportunity to capitalize on an unplanned experiment, and it is hoped that these data are structured in a way that will allow separation of oceanographic effects from the effects of heredity and environmental conditions in freshwater.

Population-Dynamics Modeling

Population-dynamics models provide unique opportunities both to synthesize multiple types of data and to evaluate the mechanisms by which environmental variation influence the production of marine resources. These characteristics make such models ideal tools for integrating the various components of the PFEL's salmon research (Figure 2) and capitalizing on the research conducted by others. For example, a working model describing possible environmental effects on marine survival and the rate of maturation in coho salmon has been developed and fitted to historical data series that include 1) estimates of smolt production sampled during outmigration, 2) counts of early and late maturing males returning to spawn, and 3) survival estimates obtained from mark-recapture experiments (Figure 9). The ability to account for variation in the observed data was highest when environmental effects on either survival or maturation were estimated, but these effects were confounded and equally good at explaining this variability. Many workers, including ones at the PFEL, have identified linkages between survival and environmental conditions in the ocean. Therefore, in an attempt to untangle the confounding in the working model, special emphasis has been placed on studying links between environmental variability and the process of maturation. Thus, the working model of coho population dynamics provided much of the impetus for the ongoing work that was described in *Correlative Modeling*.

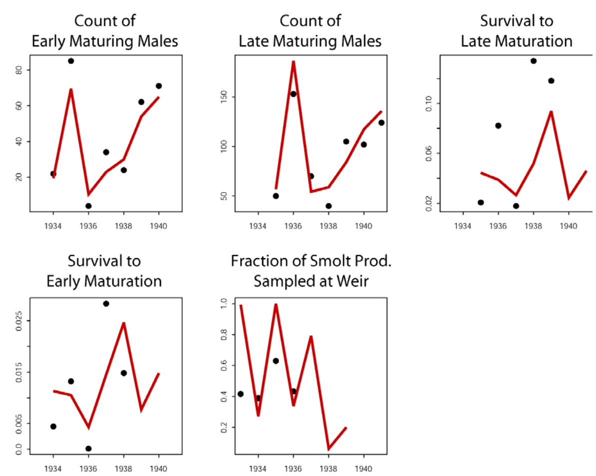


Figure 9: Results from a working model of coho salmon

Efforts are under way to achieve two proximate goals in this third program area. The first is to develop an individual-based growth model for coho salmon that is consistent with observed data. This goal derives from interest in understanding how environmental variability influences the process of maturation and recognition of the well established link between maturation and growth rate. Individuals with faster growth rates in freshwater tend to mature earlier, but there is also evidence of a negative correlation between growth rates in freshwater and saltwater. Thus, to understand how oceanographic conditions affect maturation, a growth model is being developed that explicitly accounts for habitat-specific differences in growth potential. The second proximate goal is to integrate this growth model into the working model of coho population dynamics. The working model is currently parameterized so that environmental effects on survival and maturation occur independently. A more parsimonious parameterization can be developed by first recognizing that both survival and maturation are size-dependent processes, and then using an environmentally driven growth model to account for some of the variation in these processes.

Effort is also under way to achieve two ultimate goals with population-dynamics models. The first is to determine how environmental forcing plays a role in determining the fitness consequences of the alternative life histories adopted by salmonids. Since fitness is tied to mating strategy, and individuals with different ages at maturity adopt different mating strategies (sneaking versus fighting), we are attempting to address this goal by capitalizing on development of an individual-based growth model. If a relatively simple growth model can be used to identify linkages between fitness and environmental conditions, a better understanding may be gained about the mechanisms that drive the dynamics of coho populations. The second ultimate goal is to use the modeling work to improve the scientific advice that supports the management of salmon resources. In particular, this will help align scientific advice with the expectations of stakeholders and decision makers who are conscious of environmental variation in the ocean. This objective may be accomplished by converting models developed at the PFEL into assessment tools that can both explain variation in observed data and forecast the outcome of various “environmental scenarios.”

By collaborating with members of the Center for Stock Assessment Research a cooperative program of the University of California, Santa Cruz, and the NMFS Santa Cruz Laboratory, substantial progress has been made towards the first proximate and first ultimate objectives. A summary of the results from this collaboration follows.

A form of the von Bertalanffy function is being used to model individual growth. Net growth rates are described by the term E_h-kL, where E_h relates to an animal’s rate of anabolism in habitat *h* (freshwater or saltwater) and describes this animal’s ability to gather and sequester resources from its environment. *k* is the von Bertalanffy growth coefficient and relates to the animal’s rate of catabolism (how resources gathered from the environment get used for processes other than growth). *L* is length. Assuming that *k* is set at an early point in an individual’s development, that *k* remains constant throughout life, and that an animal’s ability to gather resources in freshwater is proportional to *k* (*e.g.*, fast growers are more able to gather and sequester resources because they defend feeding territories), faster growth in freshwater results in larger smolts. Nevertheless, the growth model being developed in this research effort predicts a reversal of size rankings after the smolt transformation, and individuals that were large smolts eventually become the smallest individuals in the cohort (Figure 10). This prediction is robust to assumptions about whether or not an individual’s ability to gather and sequester resources in saltwater is also dependent on *k*. Thus, this growth model suggests a proximate mechanism for the observation that large smolts typically mature early; these fish apparently have a reduced capacity for growth at sea. The degree to which such a reduction might occur would largely depend on the difference between an animal’s abilities to gather and sequester resources in freshwater and saltwater, and interannual variation in oceanographic conditions probably affects this difference. A manuscript describing this growth model is currently undergoing internal review. It is expected that this manuscript will be submitted to the *Journal of Fish Biology* prior to the Program Review.

The growth model described above is being used to study the fitness consequences of variability in coho life history. Sex-specific functions that describe the expected lifetime reproductive success of 2-, 3-, and 4-year old spawners have been developed. The fitness functions for both males and females incorporate survival in freshwater ($S_{FW}(L)$), survival in the ocean ($S_{SW}(L)$), and a proxy for body mass (L^3). The two survival terms have size-dependent and size-independent components. For males, it is assumed that the size-specific probability of mating successfully ($P(L)$) decreases with size for animals that mature early and increases with size for animals that mature late. This assumption reflects the view that "sneaking", the mating strategy adopted by males that mature early, is facilitated by small size while "fighting", the strategy adopted by males that mature late, is facilitated by large size. The fitness function for males also incorporates an age-specific index of reproductive investment (GSI_a, gonadal somatic index at age *a*). Although early maturing males typically have smaller gonads than late maturing males, *GSI* is typically greater for early maturing males. For females, the fitness function incorporates egg biomass ($EB(L)$) and nest survival ($NS(L)$), and these are both length-dependent. Larger females produce a larger biomass of eggs, and survive on the spawning grounds for a longer period of time, thus defending their nest from possible superimposition. Fitness is the product of survival, body mass, and the various terms describing reproductive capacity.

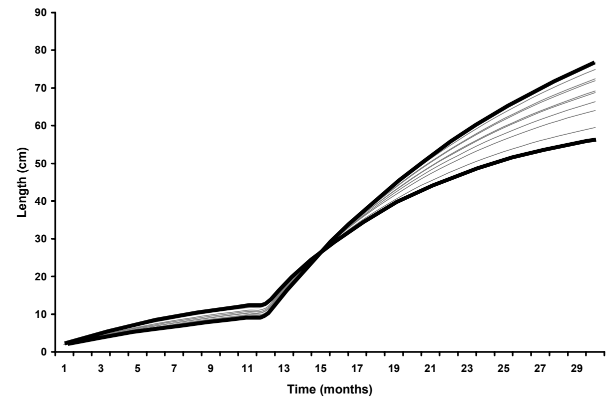
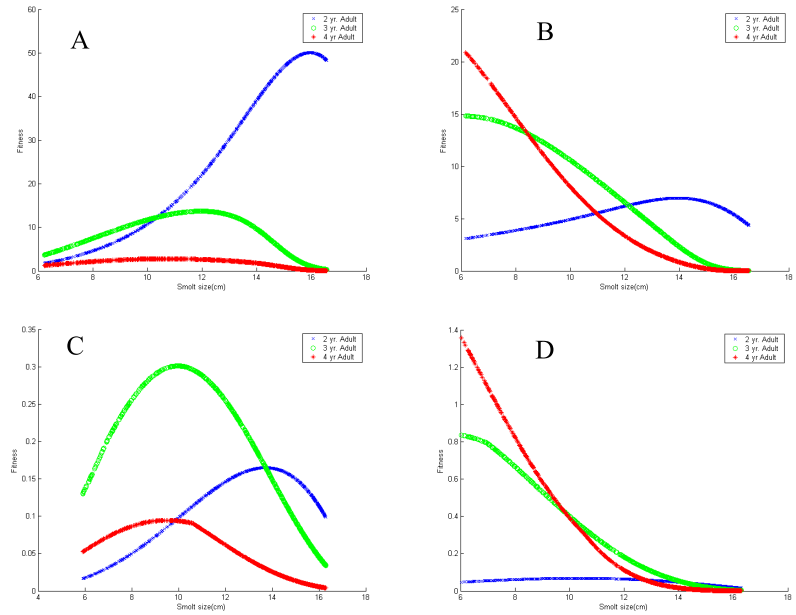


Figure 10: Simulated growth trajectories for 10 individuals with different abilities to gather resources in freshwater but the same ability to gather resources in saltwater. Ability to gather resources in freshwater is determined by size; big fish gather more resources. The smolt transformation occurs at month 12 (time elapsed since emergence from the gravel). The largest fish at the time of smolting is ultimately predicted to be the smallest fish if it returns to spawn at month 30, and this prediction is reversed for the fish that is smallest at the time of smolting. This reversal in size rankings at month 30 holds if the ability to gather resources in saltwater is also proportional to size, but the point at which small and large smolts switch ranks typically moves to the right and is smeared across a wider range of ages.

$$Fitness_{♂} = S_{FW}(L) \cdot S_{SW}(L) \cdot L^3 \cdot P(L) \cdot GSI_a$$
$$Fitness_{♀} = S_{FW}(L) \cdot S_{SW}(L) \cdot L^3 \cdot EB(L) \cdot NS(L)$$

The abundance of size-dependent terms in these functions illustrates the importance of developing an appropriate growth model. The fitness functions capture the remarkable amount of life-history variation that is observed in coho salmon (Figure 11). Although the fitness values predicted from these functions depend on a large number of parameters about which there is uncertainty, the qualitative pattern of the results is robust to this uncertainty. Large smolts can maximize their fitness by maturing early, and small smolts can maximize their fitness by delaying maturation. Although this pattern holds for both sexes, the threshold smolt length at which early maturation optimizes fitness is smaller in males than in females. This indicates that early maturation in males should be more common than in females, and is consistent with observation. These results illustrate that conditions in the ocean are also likely to affect the ultimate mechanism (fitness) influencing the age at which coho salmon mature. A second



manuscript is currently being prepared from these results, and this manuscript will be ready for internal review near the time of the Program Review.

In the future, the growth model will be integrated into the working model of coho population dynamics that was described at the beginning of this section. To accomplish this objective a parameterization of the growth model has been developed that uses time series of environmental data to account for variation in the ability of the fish to gather and sequester resources from their environment (*i.e.*, to account for variation in E_h). The environmental data can be products developed by other workers (*e.g.*, indices taken from the PFEL Live Access Server) or products developed during the present research effort (*e.g.*, indices developed as part of the correlative modeling work or observations taken directly from the archival tags). A method of fitting the growth model to observed data has also been developed. Rather than fitting to growth increments recorded for individual fish, the parameters of the growth model will be estimated by fitting to observed means and variances in age-specific size distributions. This method was developed because observations on individuals are not as common as observations on the age-specific size distributions of cohorts. Simulation methods will be used to test the estimation scheme, and it is hoped that the working model will eventually develop into a model that will be useful for assessment and forecasting.

APPENDIX A

CURRICULA VITAE

SANTA CRUZ LABORATORY
PACIFIC FISHERIES ENVIRONMENTAL LABORATORY

CURRICULUM VITAE

NAME: PETER B. ADAMS

PRESENT POSITION: Research Fishery Biologist, Fisheries Branch Chief

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PAST EXPERIENCE:	1976-present	Fishery Biologist (Research) National Marine Fisheries Service Santa Cruz and Tiburon, California
	1999-present	Research Associate Institute of Marine Science University of California, Santa Cruz
	1995-present	National Research Council Post-doctoral Fellow
	1976	Sea Grant Trainee University of California, Davis

RESEARCH INTERESTS: Modeling of populations and communities, stock assessment, dynamics of exploited populations, statistical analysis, particularly sampling, and line transect population estimates of deep slope groundfishes.

HONORS AND AWARDS: Performance Awards, 1992, 1994, 1996, 1998, 1999, 2000; Outstanding Article in Fishery Bulletin, 1980; Jastro Fellowship, University of California, Davis; Magna Cum Laude, University of Redlands.

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: ESA Biological Review Teams for coho salmon, chinook salmon, and steelhead.

SELECTED PUBLICATIONS:

Adams, P. B., E. H. Williams, K. R. Silberberg and T. E. Laidig. 1999. Southern Lingcod Stock Assessment in 1999. *In* Status of the Pacific coast groundfish fishing throughout 1999 and recommended biological catches for 2000. Pacific Fishery Management Council, Portland, Oregon. Appendix, 79 p. Pacific Fishery Management Council, Portland OR.

Adams, P. B., M. J. Bowers, H. E. Fish, T. E. Laidig, and K. R. Silberberg. 1999. Historical and Current Presence-Absence of Coho Salmon (*Oncorhynchus kisutch*) in the Central California Coast Evolutionarily Significant Unit. SWFSC Administrative Report SC-99-02. 26 p.

Adams, P. B. and D. F. Howard. 1996. Natural mortality of blue rockfish *Sebastes mystinus* during their first year in nearshore benthic habitats. Fish. Bull., U.S. 94(1):156-162.

Adams, P. B., J. H. Butler, C. H. Baxter, T. E. Laidig, K. Dahlin, and W. W. Wakefield. 1995. Population estimates of Pacific coast groundfishes from video transects and swept-area trawls. Fish. Bull., U.S. 93:446-455.

Adams, P. B. 1980. Life history patterns in marine fishes and their consequences for fisheries management. Fish. Bull., U.S. 78:1-12.

Lenarz, W. H. and P. B. Adams. 1980. Some statistical considerations of the design of trawl surveys for rockfish (Scorpaenidae). Fish. Bull., U.S. 78(3):659-674.

CURRICULUM VITAE

NAME: ARNOLD J. AMMANN

PRESENT POSITION: Research Fishery Biologist, Southwestern Fisheries Science Center

EDUCATION: Batchelors Degree University of California at Santa Barbara, CA 1994; Masters Degree University of California at Santa Cruz, CA 2000

PAST EXPERIENCE:

1994 - 1994	Research Technician GS-5 Channel Islands National Park Service Ventura, CA
1995 - 1995	Research Technician UC Santa Barbara R/V Polar Duke, Antarctica
1995 - 1998	Laboratory Assistant II Marine Science Institute Santa Barbara, CA
2000 -2000	Research Assistant University of California Santa Cruz, CA

RESEARCH INTERESTS: Population dynamics, Recruitment dynamics, Oceanography

HONORS AND AWARDS: American Legion Award 1984.

SELECTED PUBLICATIONS:

Ammann, AJ, Schroeder, DM., Love, M. 1999. Abundance, biomass, and egg production of kelp bass (*Paralabrax clathratus* inside and outside marine reserves at Santa Catalina Island, California. *In* The Ecological role of natural reefs and oil and bas production platforms on rocky reef fishes in southern California. USGS/BRD/CR 1999-0007 Pp. SB-1 to SB-3

Ammann, AJ. 2003. SMURFs: Standard Monitoring Units for the Recruitment of temperate reef Fishes. J. Exp. Mar. Biol. Ecol. *in press*

CURRICULUM VITAE

NAME: CINDY BESSEY

PRESENT POSITION: Associate Fishery Biologist, Joint Institute of Marine and Atmospheric Research, Pacific Fisheries Environmental Laboratory

EDUCATION: B.Sc., Marine Biology, Simon Fraser University, BC, Canada, 2000; M.Sc., Zoology, University of British Columbia, BC, Canada, 2003

PAST EXPERIENCE:

1997 - 2002	Research Scientist/Lab Technician, Department of Fisheries and Oceans, West Vancouver, BC
2000 - 2000	Teaching Assistant, University of British Columbia, BC

RESEARCH INTERESTS: Fisheries oceanography, correlative modeling, aquaculture research

HONORS AND AWARDS: Fully Funded Masters Degree, Department of Fisheries and Oceans, 2000-2002

SELECTED PUBLICATIONS:

Bessey, C. 2003. Reproductive performance of growth-enhanced transgenic coho salmon (*Oncorhynchus kisutch*). M.Sc. Thesis. University of British Columbia.

Bessey, C. Liley, N.R., Devlin, R.H., and Biagi, C.A. In prep. Reproductive performance of growth-enhanced transgenic coho salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences*.

CURRICULUM VITAE

NAME: ERIC P. BJORKSTEDT

PRESENT POSITION: Research Fisheries Biologist, Salmon Population Analysis Team
Research Associate, Institute of Marine Sciences, University of California, Santa Cruz
Adjunct Professor, Department of Fisheries, Humboldt State University

EDUCATION: Ph.D., Ecology, Stanford University, 1998; Honors B.A., Biology and English, University of Delaware, 1992.

PAST EXPERIENCE:

1998-present	Research Fisheries Biologist NOAA Fisheries, Southwest Fisheries Science Center Santa Cruz, California
1998	NRC Postdoctoral Research Associate NOAA Fisheries, Northwest Fisheries Science Center Seattle, Washington

RESEARCH INTERESTS: Population and metapopulation dynamics of anadromous salmonids; biological and physical processes affecting recruitment and population structure in coastal marine fishes; application of remote sensing in ecological research; life history evolution and behavioral ecology of marine and anadromous fish; theoretical and statistical ecology.

HONORS AND AWARDS: Department of Commerce Bronze Medal, 2000; Performance Award, 2000; National Research Council Postdoctoral Research Associateship, 1998; Excellence in Teaching Award, Department of Biological Sciences, Stanford University, 1995, 1997; Norman K. Wessels Award for Outstanding Performance as a Teaching Assistant, Stanford University, 1994; National Science Foundation Graduate Research Fellowship, 1993; Phi Beta Kappa University of Delaware, 1991.

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: North-Central California Coast Techinical Recovery Team (Chair); ESA Biological Review Team for Klamath Mountain Province steelhead; ESA Biological Review Team for Chinook salmon, coho salmon, chum salmon, and steelhead

SELECTED PUBLICATIONS:

Bjorkstedt, E. P., L. K. Rosenfeld, B. A. Grantham, Y. Shkedy, and J. Roughgarden (2002) Distributions of larval rockfish (*Sebastes* spp.) across nearshore fronts in a coastal upwelling region. Marine Ecology Progress Series 242: 215-228.

Spence, B.C., T.H. Williams, E. P. Bjorkstedt, and P.B. Adams (2001) Status review update for coho salmon (*Oncorhynchus kisutch*) from the Central California Coast and the California portion of the Southern Oregon/Northern California Coast Evolutionarily Significant Units. NMFS, SWFSC, Santa Cruz, 111 p.

Bjorkstedt, E. P. (2000) DARR (Darroch Analysis with Rank-Reduction): A method for analysis of stratified mark-recapture data from small populations, with application to estimating abundance of smolts from outmigrant trap data. U.S. Dep. Commer., NOAA, NMFS, SWFSC, Admin. Rep., Santa Cruz, SC-00-02. 28 p.

McElhany P., Ruckelshaus M., Ford M. J., Wainwright T., Bjorkstedt E. P. (2000) Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units. U.S. Depart. Commer., NOAA Technical Memorandum NMFS-NWFSC-42, 156 p.

Bjorkstedt, E. (2000) Stock-recruitment relationships for life cycles that exhibit concurrent density dependence. Canadian Journal of Fishery and Aquatic Sciences 57(2): 459-467.

CURRICULUM VITAE

NAME: DAVID A. BOUGHTON

PRESENT POSITION: Research Ecologist, Salmon Population Analysis Team

EDUCATION: Ph.D., Ecology, University of Texas Austin, 1998. A.B. magna cum laude, Ecology and Systematics, Cornell University, 1988.

PAST EXPERIENCE:

2001-present	Research Ecologist NOAA Fisheries, Southwest Fisheries Science Center Santa Cruz, California	
1999-2001	Research Ecologist USDA Forest Service, Pacific NW Research Station Corvallis, Oregon	
1998-1999	Ecologist US EPA, Office of Research and Development Research Triangle Park, North Carolina	
1988-1991	Programmer/Taxonomist Ichthyology, California Academy of Sciences San Francisco, California	

RESEARCH INTERESTS: Population and metapopulation dynamics; local adaptation of animal behavior and life history, especially dispersal systems; complex life histories; landscape ecology. Mathematical ecology, evolution, statistics.

HONORS AND AWARDS: USDA Science Findings Award, 2001. NSF International Postdoctoral Fellowship, 1998. Ecological Society of America Buell Award, 1998 (honorable mention). Sigma Xi, University of Texas, 1997. Annual Symposium Invitee, Environmental Defense Fund, 1997. STAR Fellow, US Environmental Protection Agency, 1996. National Science Foundation, dissertation improvement grant, 1995. University of Texas Austin, continuing fellowship, 1995. National Science Foundation, predoctoral fellowship 1991. Distinction in all subjects, Cornell University (1988)

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: Chair, So. Calif. Recov. Domain TRT, pending. Modelling Workgroup, Survey and Manage Prog. (USDA and BLM), 1999-2000. Chair, Soc. Conserv. Biol., Univ. Texas Chapter 1991-92.

SELECTED PUBLICATIONS:

Boughton, D.A. & U. Malvadkar. 2002. Extinction risk in successional landscapes subject to catastrophic disturbances. Conservation Ecology 6(2): 2.

Boughton, D.A. 2000. The dispersal system of a butterfly: a test of source-sink theory suggests the intermediate-scale hypothesis. American Naturalist 145: 131 - 144.

Boughton, D.A. 1999. Empirical evidence for source-sink dynamics in a butterfly: Temporal barriers and alternative states. Ecology 80(8): 2727 - 2739.

Boughton, D.A., B.B. Collette & A.R. McCune. 1991. Heterochrony in jaw morphology of needlefishes (Belonidae: Teleostei). Systematic Zoology 40(3): 329 - 354.

CURRICULUM VITAE

NAME: CHRISTOPHER J. DONOHOE

PRESENT POSITION: Staff Research Associate IV

EDUCATION: Ph.D., Oregon State University (Fisheries Science). 2000; M.S., San Diego State University (Biology; Ecology), 1990; B.S., Florida Institute of Technology (Marine Biology), 1980.

PAST EXPERIENCE:

	2002 - present	Staff Research Associate IV University of California, Santa Cruz Santa Cruz, CA
	1991 - 2000	Graduate Research Assistant / Teaching Assistant / Graduate Student Department of Fisheries and Wildlife, Oregon State University Corvallis, OR
	1985-1991	Research Assistant Department of Biology, San Diego State University San Diego, CA.
	1980-1982	Research Assistant Harbor Branch Oceanographic Institution Fort Pierce, FL

RESEARCH INTERESTS: Relationships among life history forms in salmonids, early life history strategies of fishes, environmental and ontogenetic variation in otolith microchemistry, fisheries oceanography and recruitment of coastal fishes, age and growth of fishes.

HONORS AND AWARDS: AIFRB Research Assistance Award, 1996; ASIH Best Student Paper, runner up, 1994.

SELECTED PUBLICATIONS:

Donohoe, C. J., and D. F. Markle. in prep. Metamorphosis and relationships to otolith microstructure and growth in Pacific sanddab, *Citharichthys sordidus* (Paralichthyidae).

Donohoe, C. J., and D. F. Markle. in prep. Settlement, distribution, and abundance of age-0 Pacific sanddab (*Citharichthys sordidus*) on the Oregon continental shelf.

Donohoe, C. J., and D. F. Markle. in prep. Ontogenetic and individual variation in otolith microchemistry of two recently-settled flatfishes, Dover sole (*Microstomus pacificus*) and Pacific sanddab (*Citharichthys sordidus*).

Donohoe, C. J., and D. F. Markle. in prep. Sources of variation in time series of otolith growth of settling Pacific sanddab, C*itharichthys sordidus* (Paralichthyidae).

Toole, C.L., D.F. Markle, and C.J. Donohoe. 1997. Settlement timing, distribution, and abundance of Dover sole (*Microstomus pacificus*) on an outer continental shelf nursery area. Canadian Journal of Fisheries and Aquatic Sciences. 54: 531-542.

Donohoe, C.J. 1997. Age, growth, distribution, and food habits of recently settled white seabass, *Atractoscion nobilis*, off San Diego County, California. Fishery Bulletin. 95:709-721.

CURRICULUM VITAE

NAME: HEIDI E. FISH

PRESENT POSITION: Research Fishery Biologist, Salmon Population Analysis Team

EDUCATION: B.S., Zoology, California State University Long Beach, 1983.

PAST EXPERIENCE:

1997-present	Research Fishery Biologist National Marine Fisheries Service Santa Cruz, California
1996	Biological Science Technician National Marine Fisheries Service Tiburon California
1990-1996	Fish and Wildlife Scientific Aide California Department of Fish and Game Long Beach and Menlo Park, California

RESEARCH INTERESTS: Salmon life history and stream survey methods.

HONORS AND AWARDS: Certificate of Recognition, 1997.

PROFESSIONAL AFFILIATIONS: American Fisheries Society

SELECTED PUBLICATIONS:

Laidig, Thomas E., Peter B. Adams, Kelly R. Silberberg and Heidi E. Fish. 1997. Conversions between total, fork and standard lengths for lingcod, *Ophiodon elongatus*. California Fish Game 83:128-129.

Adams, Peter B., Michael J. Bowers, Heidi E. Fish, Thomas E. Laidig and Kelly R. Silberberg. 1999. Historical and Current Presence-Absence Data of Coho Salmon (*Onchorhynchus kisutch*) in the Central California Coast Evolutionarily Significant Unit. U.S. Dep. Commer., NOAA, NMFS, SWFSC Admin. Rep., Tiburon, SC-99-02.

CURRICULUM VITAE

NAME: ELLEN V. FREUND

PRESENT POSITION: Research Fishery Biologist, Salmon Ecology Team

EDUCATION: Ph.D., Biological Sciences, Stanford University, 1999; B.A., Biology, Brown University, 1989.

PAST EXPERIENCE:

2003- present	Research Fishery Biologist NMFS/SWFSC Santa Cruz, California
1999-2002	Post-doctoral Associate/ Preceptor Harvard University Cambridge, Massachusetts
1993-1999	Graduate Student/ Teaching Assistant Stanford University Stanford, California
1990-1992	Research Assistant Immulogic Pharmaceutical Corporation Palo Alto, California

RESEARCH INTERESTS: Physiological ecology, comparative zoology, functional morphology of vertebrates, specifically fish (teleosts and elasmobranchs).

HONORS AND AWARDS: Excellence in Teaching, Organismic and Evolutionary Biology Department, Harvard University, 2000 and 2001; Scholander Award, 2nd place, American Physiological Society, 1999; National Science Foundation Predoctoral Fellowship, 1994; Magna Cum Laude and Honors, Brown University, 1989; Sigma Xi, Brown University, 1989.

SELECTED PUBLICATIONS:

Marcinek, D.J., S.B. Blackwell, H. Dewar, E.V. Freund, C. Farwell, D. Dau, A.C. Seitz, B.A. Block. 2001. Depth and muscle temperature of Pacific bluefin tuna examined with acoustic and pop-up satellite archival tags. Marine Biology, 138(4): 869-885.

Shiels, H.A., E.V. Freund, A.P. Farrell and B.A. Block, 1998. The sarcoplasmic reticulum plays a major role in isometric muscle contraction in atrial muscle from yellowfin tuna. Journal of Experimental Biology, 202: 881-890.

Block, B.A., J. Keen, B. Castillo, R. Brill, H. Dewar, E.V. Freund, D.J. Marcinek and C. Farwell, 1996. Environmental preferences of yellowfin tuna (*Thunnus albacares*) at the northern extent of its range. Marine Biology, 130: 119-132.

Brill, R.W., B.A. Block, C. Boggs, K. Bigelow, E.V. Freund and D.J. Marcinek, 1999. Horizontal and vertical movements of adult yellowfin tuna near the Hawaiian islands recorded using ultrasonic telemetry: Implications for the physiological ecology of pelagic fishes. Marine Biology, 133(3): 395-408.

Wasser, J.S., E.V. Freund, L.A. Gonzalez and D.C. Jackson, 1990, Force and acid-base state of turtle cardiac tissue exposed to combined anoxia and acidosis, American Journal of Physiology, 259(1 part 2): R15-R20.

Powell, T.J., J. Quan, E. Freund and W.C.A. Van Schooten, 1996, Activation of T cells by autoantigen immobilized by specific antibodies, Methods (Orlando), 9(3): 453-457.

Goldstein, L., S.R. Brill and E.V. Freund, 1990, Activation of taurine efflux in hypotonically stressed elasmobranch cells: Inhibition by stilbene disulfonates. Journal of Experimental Zoology, 254(1): 114-118.

CURRICULUM VITAE

NAME: JOHN CARLOS GARZA

PRESENT POSITION: Team Leader/Research Geneticist, Molecular Ecology Team

EDUCATION: Ph.D., Integrative Biology, University of California, Berkeley, 1998; M.S., Biology, University of California, San Diego, 1991; B.S., Biology, University of California, San Diego, 1990.

PAST EXPERIENCE:

	2001-present	Assistant Adjunct Professor of Ocean Sciences University of California, Santa Cruz
	2000-present	Research Fellow Institute of Marine Sciences University of California, Santa Cruz
	1998-1999	Visiting Scientist Laboratoire Génome et Populations University of Montpellier, France

RESEARCH INTERESTS: Molecular Ecology; Population Genetics; Phylogeography; Genetic Basis of Complex Traits; Genetics of Stock Management

HONORS AND AWARDS: National Science Foundation Postdoctoral Fellowship,1998; University of California President's Postdoctoral Fellowship, 1998; Sigma Xi Grant in Aid of Research, 1997; UCB Chancellor's Dissertation Year Fellowship, 1997; Ford Foundation Dissertation Year Fellowship, 1997; National Science Foundation Doctoral Dissertation Improvement Grant, 1996; UCB Vice Chancellor of Research Dissertation Grant, 1996; UC Natural Reserve System Mildred Mathias Research Grant, 1993; Ford Foundation Predoctoral Fellowship, 1992-96; UCSD Chancellor's Volunteer Award, 1991; Phi Beta Kappa Honor Society, 1989; UCSD Alumni Association: Scholar of the Year (Twice), 1988-90; UCSD Provost's Honor Roll (5 times), 1987-90.

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: ESA Salmonid Central California Coast Technical Recovery Team, 2001-03; Saltonstall-Kennedy Grant Reviewer, 2001; Russian River Coho Salmon Recovery Work Group, 2001-03.

SELECTED PUBLICATIONS:

Wlasiuk G, Garza JC, Lessa E (2003) Genetic and geographic differentiation in the Rio Negro tuco-tuco (*Ctenomys rionegrensis*): distinguishing historical and contemporary gene flow. Evolution: 57:913-926.

Garza JC, Williamson E (2001) Detection of reduction in population size using data from microsatellite DNA. Molecular Ecology 10: 305-318

Garza JC, Desmarais E (2000) Derivation of a simple microsatellite locus from a compound ancestor in the genus *Mus*. Mammalian Genome 11: 1117-1122.

Weber DS, Stewart BS, Garza JC, Lehman N (2000) An empirical genetic assessment of the severity of the northern elephant seal population bottleneck Current Biology 10: 1287-1290 (cover photo).

Garza JC, Dallas J, Duryadi D, Gerasimov S, Croset H, Boursot P (1997) Social structure of the Mound-building mouse, *Mus spicilegus*, revealed by genetic analysis with microsatellites. Molecular Ecology 6: 1009-1017.

Garza JC, Freimer NB (1996) Homoplasy for size at microsatellite loci in humans and chimpanzees. Genome Research 6: 211-217.

Garza JC, Slatkin M, Freimer NB (1995) Microsatellite allele frequencies in humans and chimps with implications for constraints on allele size. Molecular Biology and Evolution 12: 594-603.

CURRICULUM VITAE

NAME: ELIZABETH ALICE GILBERT

PRESENT POSITION: Research Molecular Geneticist

EDUCATION: Master of Arts Degree, San Francisco State University, 2001; Bachelor of Science Degree, Oregon State University, 1989. Recent coursework: Summer Institute in Statistical Genetics, NCSU, 2003.

PAST EXPERIENCE:

	2001 - present	Research Molecular Geneticist NOAA/NMFS Santa Cruz, California
	2001 - 2001	Marine Scientist Aquatic Farms Santa Cruz, California
	2001 - 2001	Research Technician San Francisco State University San Francisco, California
	1998 - 2001	Graduate Assistant San Francisco State University San Francisco, California

RESEARCH INTERESTS: Population genetics and phylogeography of marine and anadromous fishes, larval recruitment, molecular ecology.

HONORS AND AWARDS: Myers Oceanographic and Marine Biology Trust research grant, 1998; Lerner-Gray Fund research grant, 1999; Sigma Xi research grant, 1999.

SELECTED PUBLICATIONS:

Gilbert, E. A. 2000. Molecular genetic analysis of temporal recruitment pulses in juvenile kelp rockfish. Master's Thesis, San Francisco State University.

CURRICULUM VITAE

NAME: CHURCHILL BRAGAW GRIMES

PRESENT POSITION: Director, Santa Cruz Laboratory

EDUCATION: B.S. and M.S. Biology, East Carolina University, Greenville, North Carolina, 1967, 1971; Ph.D., Marine Sciences, University of North Carolina, Chapel Hill, 1976.

PAST EXPERIENCE:

	1993-1998	Laboratory Director
	1984-1993	Fishery Ecologist National Marine Fisheries Service Panama City, Florida
	1983-1984	Associate Professor of Marine Fisheries
	1977-1983	Assistant Professor of Marine Fisheries Rutgers University New Brunswick, New Jersey

RESEARCH INTERESTS: Life history, population dynamics, fishery ecology, and recruitment dynamics.

HONORS AND AWARDS: Marine Science Fellowship, University of North Carolina, 1972-1973; Sigma XI; NMFS Outstanding Publication Award, *Fishery Bulletin*, Honorable Mention 1984; Outstanding Performance Award, 1987-1988, 1993-1996; Commendable Performance Award, 1989-1992; NOAA Bronze Medal 1996; American Institute of Fishery Research Biologists: Associate 1975, Member 1980, Fellow 1990; American Fisheries Society: Florida Chapter, Runner-up, Outstanding Presentation at Annual Meeting, February 1992 and 1993; Southern Division, Outstanding Achievement Award, 1996.

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: National Center for Ecological Analysis and Synthesis, Open Populations Working Group, 2000-01; MexUS-Pacifico, Coastal Species Working Group Chair, 2000-01; NOAA Science Advisory Board, Science Under Multiple Mandates Panel discussant; Monterey Bay National Marine Sanctuary, Research Activities Panel, 2000-present; East Carolina University, College of Arts & Science, Advancement Council, 2000-present.

SELECTED PUBLICATIONS:

Gieger, S.P., J.J. Tores and C.B. Grimes. Measures of physiological condition in larval anchovies, *Anchoa hepsetus*, collected in the discharge plume of the Mississippi River during the flood of 1993. Mar. Ecol. Prog. Sci. (in press).

Yoklavich, M. M., C. B. Grimes, and W. W. Wakefield. 2003. Using laser line scan imaging technology to assess deepwater seafloor habitats in the Monterey Bay National Marine Sanctuary. Marine Technology Society Journal 37(1):18-26.

Sponangle, S., R.K. Cowan, A. Shanks, S.G. Morgan, J.M. Leis, J. Pineda , G. Boehlert, M.J. Kingsford, K. Lindeman, C.B. Grimes, and J.L. Munro. 2002. Predicting self-recruitment in marine populations: biophysical correlates and mechanisms. Bull. Mar. Sci. 70(1)supl.:341-375.

Allman, R.J. and C.B. Grimes. 2002. Temporal and spatial dynamics of spawning, settlement, and growth of gray snapper (*Lutjanus griseus*) from the West Florida shelf as determined from otolith microstructures. Fishery Bulletin 100(3):391-403.

DeVries, D.A., C.B. Grimes, and M.H. Prager. 2002. Using otolith shape analysis to distinguish eastern Gulf of Mexico and Atlantic Ocean stocks of king mackerel. Fish. Res. 57:51-62.

Levin, P.S. and C.B. Grimes. 2002. Reef fish ecology and grouper conservation and management. In: P. F. Sale (ed.), Coral reef fishes: dynamics and diversity in a complex ecosystem, p. 377-389. Academic Press.

Grimes, C.B. 2001. Fishery production and the Mississippi River discharge. Fisheries 26:17-26.

CURRICULUM VITAE

NAME: JEFFREY HARDING

PRESENT POSITION: Research Fishery Biologist, Salmon Ecology Team

EDUCATION: MS, Zoology, Oregon State University, 1993; BA, General Biology, University of California, San Diego, 1985.

PAST EXPERIENCE:

2002 - present	Research Fishery Biologist NMFS/SWFSC Santa Cruz Laboratory Santa Cruz, CA
2000 - 2001	Instructor (Biology, Marine Biology, Environmental Science) Monterey Peninsula College Monterey, CA
1995 - 2002	Marine Biological Technician and Data Analyst University of California Santa Cruz and Santa Barbara, CA
1994	Instructor, Oregon Inst. Marine Biology (University Of Oregon) Charleston, Oregon
1989 - 1993	Graduate Teaching Assistant and Graduate Research Assistant Oregon State University Corvallis, OR

RESEARCH INTERESTS: Community ecology of coastal marine ecosystems, especially temperate rocky reefs, kelp forests, and coral reefs. Current research focus is growth, physiology, and trophic ecology of Pacific salmonids. In particular, my goals as a field biologist are to study and evaluate the links between physical oceanographic conditions, coastal oceanic food webs, and juvenile salmon growth and survival in the bays, estuaries, and coastal ocean of central California.

HONORS AND AWARDS: Lerner-Gray Fund for Marine Research, 1992; Sigma Xi Grants-in-Aid of Research, 1992; OSU Zoology Research Fund, 1991, 1992, 1993.

PRESENTED PAPERS:

Mate guarding as a mechanism for pairing in a coral reef fish. Western Society of Naturalists, Newport, OR. 1993.

Pair formation and stability in a monogamous coral reef fish, the cleaning goby *Gobiosoma evelynae*. Pacific Ecology Conference, Friday Harbor Laboratories, WA. 1992.

Site fidelity, pair stability, and behavior of the Caribbean cleaning goby *Gobiosoma evelynae*. OSU Biology Graduate Student Symposium, Newport, OR. 1991.

CURRICULUM VITAE

NAME: SEAN A. HAYES

PRESENT POSITION: Research Assistant I

EDUCATION: Ph.D. Biology, Fall 2002; MS. Biology, 1998 University of California Santa Cruz. B.S. Biology, 1994. Cornell University. A.S. Fisheries and Wildlife Technology, 1991, State University of New York, Cobleskill.

PAST EXPERIENCE:	2002 - present	Research Assistant I/III JIMO/NMFS Santa Cruz, Ca
	2001 -2001	Ecologist, GS 11 NMFS Honolulu, HI
	1994-2001	Graduate Student University of California Santa Cruz Santa Cruz, CA

RESEARCH INTERESTS: Behavioral and physiological ecology of salmonids and pinnipeds

HONORS AND AWARDS: American Museum of Natural History Lerner-Gray Award 1997; American Museum of Natural History Theodore Roosevelt Award 1998; American Cetacean Society Research Award 2000; Animal Behavior Society Research Grant 2000; Earl & Ethel Myers Oceanographic and Marine Biology Award 1997, 1998, 2000; GAANN Graduate Fellowship 1995-1998, 2001; SigmaXi Award 1998.

SELECTED PUBLICATIONS:

Costa, D. P., Crocker, D. E., Gedamke, J., Webb, P. M., Houser, D., Blackwell, S., Waples, D., Hayes, S. A. & Le Bouef, B. J. 2003. The effect of a low-frequency sound source (acoustic thermometry of the ocean climate) on the diving behavior of juvenile northern elephant seals, *Mirounga angustirostrus*. J. Acoust. Soc. Am., 113, 1155-1165.

Costa, D. P. & Hayes, S. A. 2000. Underwater acoustic pollution. In: McGraw-Hill Yearbook of Science and Technology, pp. 405-407. New York: McGraw-Hill.

Hayes, S. A., Costa, D. P., Harvey, J. T. & Le Boeuf, B. J. Aquatic mating strategies of the male Pacific harbour seal (*Phoca vitulina richardsi*). *In prep* for submission to Marine Mammal Science.

Hayes, S. A., Costa, D. P., Harvey, J. T., Le Boeuf, B. J. & Garza, J. C. Evaluating the influence of the environment on reproductive success in an aquatic mating phocid. *In prep* for submission to Molecular Ecology.

Hayes, S. A., Kumar, A., Costa, D. P., Mellinger, D. K., Harvey, J. T., Southall, B. L. & Boeuf, B. J. L. *In press.* Evaluating the function of male vocalizations in the harbor seal (*Phoca vitulina*) through playback experiments. Animal Behaviour.

Hayes, S. A., Mellinger, D. K., Costa, D. P., Croll, D. A. & Borsani, J. F. 2000. An inexpensive passive acoustic system for recording and localizing wild animal sounds. J. Acoust. Soc. Am., 107, 3552-3555.

Van Parijs, S. M., Corkeron, P. J., Harvey, J. T., Hayes, S. A., Mellinger, D. K., Rouget, P. A., Thompson, P. M., Wahlberg, M. & Kovacs, K. M. 2003. Patterns in the vocalizations of male harbor seals. J. Acoust. Soc. Am., 113, 3403-3410.

SELECTED PRESENTATIONS:
Hayes, S. A., Hanson, C. V., Bond, M. H. & MacFarlane, R. B. 2003. Seasonal fluctuations of Na^+, K^+ -ATPase in Central California salmonids prior to ocean entry. In: Western Division of the American Fisheries Society. San Diego, CA: AFS.

CURRICULUM VITAE

NAME: K KELLY HILDNER

PRESENT POSITION: Staff Research Associate III

EDUCATION: B.S. Ecology, Animal Behavior, and Evolution, University of California San Diego, 1991; Ph.D. Biology, University of California Santa Cruz, 2000

PAST EXPERIENCE:

2002 - present	Staff Research Associate III
2001 - 2002	Postgraduate Researcher
2001	Course Assistant
1991 - 1999	Teaching Assistant
1994 - 1995	Research Associate University of California Santa Cruz Santa Cruz, CA
1993	Researcher/Writer The Conservation Fund Santa Cruz, CA

RESEARCH INTERESTS: Habitat restoration, conservation planning, habitat fragmentation and genetic variability loss.

HONORS AND AWARDS: Elected - Sierra Club, Santa Cruz Group Executive Committee, 2003; Chair, Sierra Club, Santa Cruz Group Growth Management Committee, 2002-present; GAANN fellowship, 1996-1998; Sigma Xi Grant-in-Aid of Research, 1996; Biology Department Summer Fellowship, UC Santa Cruz, 1996; Sigma Xi Grant-in-Aid of Research, 1995; American Society of Mammalogists Grant-in-Aid of Research, 1995; Mathias Graduate Student Research Grant, 1994; Environmental Systems Research Institute course scholarships, 1992; Regent's fellowship, UCSC, 1991; Muir Outstanding Scholar Award, UCSD, 1991; Phi Beta Delta National Honor Society, 1991; Golden Key National Honor Society - Community Service Coordinator, UCSD, 1990; John Muir College (UCSD) Caledonian Honor Society, 1990; Education Abroad Program Scholarship, UCSD, 1990; Alumni Scholar, UCSD, 1989

SELECTED PUBLICATIONS: Note: Some publications and presentations are under the name K. Kelly Moran

Hildner, K. K., and Soulé, M. E. In prep. Relationship between the energetic cost of burrowing and genetic variability among populations of the pocket gopher, *Thomomys bottae*.

Hildner, K. K., Soulé, M. E., Min, M. S. , Foran, D. R. 2003. The relationship between genetic variability and growth rate among populations of the pocket gopher, *Thomomys bottae*. Conservation Genetics 4(2):

Hildner, K.K. 2000. The Relationship Between Genetic Variability and Physiological Fitness Among Populations of the Pocket Gopher, *Thomomys bottae*, and its Implications for Conservation. Dissertation, University of California, Santa Cruz.

Doak, D. F., et al. [including K. Moran]. 1996. Natural Resources Management Plan: Naval Industrial Reserve Ordinance Plant, Santa Cruz.

Moran, K. K. 1994. Wildlife Corridors and Pipeline Corridors: A Comparative Analysis. Pp. 99-120 in K. G. Hay (ed.), Greenways, Wildlife and Natural Gas Pipeline Corridors: New Partnerships for Multiple Use.

Moran, K. K. 1994. Using Geographic Information Systems to Site Pipeline Corridors. Pp. 121-128 in K. G. Hay (ed.), Greenways, Wildlife and Natural Gas Pipeline Corridors: New Partnerships for Multiple Use.

CURRICULUM VITAE

NAME: JEFFERSON T. HINKE

PRESENT POSITION: Fishery Biologist, Joint Institute for Marine and Atmospheric Research, Pacific Fisheries Environmental Laboratory

EDUCATION: B.S., Zoology, Environmental Aspects of Conservation, University of Wisconsin-Madison, 1999; M.S., Zoology, University of Wisconsin-Madison, Center for Limnology, 2001

PAST EXPERIENCE: 2002 Research Intern, National Center for Ecological Analysis and Synthesis, Santa Barbara, CA

RESEARCH INTERESTS: Fish habitat, food webs, trophic interactions, population dynamics

HONORS AND AWARDS: Phi Kappa Phi, 1999; Research Experience for Undergraduates grant for research at the University of Notre Dame Environmental Research Center, 1998

SELECTED PUBLICATIONS:

Hinke, J.T., G.M. Watters, G. Boehlert, and P. Zedonis. In prep. Comparison of autumn ocean habitat use by Chinook salmon in coastal Oregon and California waters. *Marine Ecology Progress Series*.

Hinke, J.T., I.C. Kaplan, K. Aydin, G.M. Watters, R. J. Olson, and J.F. Kitchell. Submitted. Visualizing the food-web effects of fishing for tunas in the Pacific Ocean. *Conservation Ecology*.

Hinke, J.T., T.E. Essington, and J.F. Kitchell. Submitted. Size, density, and the predator-prey interactions of juvenile fishes in lakes. *Ecology*.

Fisher, D.R., B.W. Hale, J.T. Hinke, and C.A. Overdevest. 2002. Social and ecological responses to climatic change: towards and integrative understanding. *International Journal of Environment and Pollution*. 17: 323-326.

Greenfield, B. K., D. B. Lewis, and J. T. Hinke. 2002. Effect of injury in salt marsh periwinkles (*Littoraria irrorata* [Say, 1822]) on resistance to future attacks by blue crabs (*Callinectes sapidus* [Rathbun, 1896]). *American Malacological Bulletin*. 17: 141-146.

CURRICULUM VITAE

NAME: RACHEL C. JOHNSON

PRESENT POSITION: Research Fishery Biologist, Salmon Ecology Team - Student Career Experience Program

EDUCATION: Ph.D. candidate, Ecology and Evolutionary Biology, University of California, Santa Cruz; B.A., Biology, Wellesley College, Massachusetts, 1997.

PAST EXPERIENCE:	1999-present	Graduate Researcher
	1999-2000	Teaching Assistant University of California, Santa Cruz
	1998	Zooplankton Identification Specialist SWFSC Antarctic Marine Living Resources Group South Shetland Islands, Antarctica
	1998	Taxonomist California Academy of Sciences San Francisco, California
	1997	Tropical Marine Ecologist/ Instructor International Zoological Expedition Belize, Central America
	1995-1997	Marine Biology Teaching Assistant Wellesley College, Massachusetts

RESEARCH INTERESTS: Applied marine ecology, population biology, fishery ecology, metapopulation dynamics, and application of stable isotopes as tracers of spatial structure in populations.

HONORS AND AWARDS: Myers Oceanographic and Marine Biology Scholarship, 2001; Honorable Mention, NSF Graduate Research Fellowship, 1998 &1999.

SELECTED PUBLICATIONS:

Johnson, R.C., C.B. Grimes and C.F. Royer. (In Prep). Discrimination of hatchery and wild chinook salmon (Onchorynchus tshawysha) in the California Central Valley using otolith microstructure.

Johnson, R.C., and R.B. MacFarlane. (In Prep). Estuary use and growth history of juvenile Chinook salmon from the California Central Valley juvenile in the San Francisco Bay Estuary.

Jensen, G.C. and R.C. Johnson. 1999. Reinstatement and further description of *Eualus subtilis* Carvacho & Olsen, and comparison with *E. lineatus* Wicksten & Butler (Crustacea: Decapoda: Hippolytidae). *Proceeding of the Biological Society of Washington* 112(1): 133-140.

Loeb, V., R.C. Johnson and E. Linen. (In Prep). Distribution of krill, salp and other zooplankton taxa around Elephant Island during the 1998 Austral summer. *Antarctic Journal.*

CURRICULUM VITAE

NAME: STEVEN T. LINDLEY

PRESENT POSITION: Ecologist, Salmon Population Analysis Team

EDUCATION: Ph.D. (1994) Duke University; B.A. (1989, Aquatic Biology, with Honors and Distinction); University of California at Santa Barbara.

PAST EXPERIENCE:

1996-present	Ecologist NMFS/SWFSC, Santa Cruz/Tiburon Laboratory	
1995-1996	Research Associate Marine Laboratory, Duke University	
1994-1995	Postdoctoral Fellow, Stanford University	

RESEARCH INTERESTS: Population biology, ecosystem ecology, numerical and statistical modeling, biological oceanography, stable isotopes, biotelemetry.

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: Central Valley Chinook and Steelhead Technical Recovery Team (chair); West Coast Chinook Salmon Status Review and Biological Review Teams; Green Sturgeon Biological Review Team, Candidate Species Budget Panel.

SELECTED PUBLICATIONS:

Lindley, S. T. 2003. Estimation of population growth and extinction parameters from noisy data. Ecological Applications 13: 806-813.

Lindley, S. T. and M. H. Mohr. 2003. Predicting the impact of striped bass (*Morone saxatilis*) population manipulations on the persistence of winter-run chinook salmon (*Oncorhynchus tshawytscha*). Fishery Bulletin 101:321-331

Lindley, S. T., M. S. Mohr and M. H. Prager. 2000. Monitoring protocol for Sacramento River winter chinook salmon: application of statistical power analysis to recovery of an endangered species. Fishery Bulletin 98: 759-766.

Brodeur, R. D., G. W. Boehlert, E. Casillas, M. B. Eldridge, J. H. Helle, W. T. Peterson, W. R. Heard, S. Lindley and M. H. Schiewe. 2000. A coordinated research plan for estuarine and ocean research on Pacific salmon. Fisheries 25: 7-16.

Chai, F., S. T. Lindley, J. R. Toggweiler, and R. T. Barber. 2000. Testing the importance of iron and grazing in the maintenance of the high nitrate condition in the equatorial Pacific Ocean: a physical-biological model study. In: The Changing Ocean Carbon Cycle: a midterm synthesis of the Joint Global Ocean Flux Study. R. B. Hanson, H. W. Ducklow, and J. G. Field (eds). International Geosphere-Biosphere Programme Book Series 5. Cambridge University Press.

Bender, M., J. Orchardo, M. Dickson, R. Barber and S. Lindley. 1999. In vitro O_2 fluxes compared with ^{14}C production and other rate terms during the JGOFS Equatorial Pacific experiment. Deep Sea Research 46: 637-654.

Lindley, S. T. and R. T. Barber. 1998. Phytoplankton response to natural and experimental iron enrichment. Deep Sea Research. 45: 1135-1150

Myers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F. W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. Status review of chinook salmon from Washington, Idaho, Oregon, and California. U. S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-35, 443 p.

CURRICULUM VITAE

NAME: R. BRUCE MacFARLANE

PRESENT POSITION: Salmon Ecology Team Leader

EDUCATION: Ph. D., Oceanography, Florida State University, 1980; M.S., Oceanography, Florida State University, 1970; B.S., Zoology, Pennsylvania State University, 1968.

PAST EXPERIENCE:

	1980-present	Research Fishery Biologist NMFS/SWFSC Santa Cruz and Tiburon, California
	1978-1980	Instructor, Department of Oceanography Florida State University Tallahassee, Florida

RESEARCH INTERESTS: Salmon biology, physiological ecology, biochemistry of fishes, pollutant dynamics, biological/chemical oceanography.

HONORS AND AWARDS: Best Publication in Fishery Bulletin, 2002; National Research Council Post-doctoral Fellow Advisor, 1998-present; Outstanding Performance Award, NOAA/NMFS/SWFSC, 1984, 1990, 1994-5, 1997, 1999-2000; Quality Step Increase, NOAA/NMFS/SWFSC, 1990, 1998; Sustained Superior Performance Award, 1985, 1986; Commendation for Technical Advice, Aquatic Habitat Program, Resolution #85-16, San Francisco Bay Regional Water, Quality Control Board, Oakland, California, 1985; Society of Sigma Xi Doctoral Assistance Grant.

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: Central Valley Technical Recovery Team; California Ocean Observation System (Prop 40) Scientific Advisory Panel; San Francisco Estuary Project, Technical Advisory Committee, U.S. EPA, Region IX, San Francisco; CALFED Technical Advisory Group; NMFS/CDFG Anadromous Fish Hatchery Review Committee.

SELECTED PUBLICATIONS:

Eldridge, M. B., E. C. Norton, B. M. Jarvis, and R. B. MacFarlane. 2002. Energetics of early development in the vivaparous yellowtail rockfish. Journal of Fish Biology 61:1122-1134.

MacFarlane, R. B., S. Ralston, C. Royer, and E. C. Norton. 2002. Influences of the 1997- 1998 El Niño and 1999 La Niña on juvenile chinook salmon in the Gulf of the Farallones. PICES Scientific Report No. 20:25-29.

MacFarlane, R.B. and E.C. Norton. 2002. Physiological ecology of juvenile chinook salmon (*Oncorhynchus tshawytscha*) at the southern end of their distribution, the San Francisco Estuary and the Gulf of the Farallones, California. Fish. Bull. 100:244-257.

Norton, E.C., R.B. MacFarlane, and M.S. Mohr. 2001. Lipid class dynamics during development in early life stages of shortbelly rockfish and their application to condition assessment. Journal of Fish Biology 58:1010-1024.

MacFarlane, R.B. 2000. Use of the San Francisco Estuary by juvenile chinook salmon. In *Fish migration and passage*, (J. Cech, Jr., S. McCormick, and D. MacKinlay, eds.) International Congress on the Biology of Fish, American Fisheries Society, pp. 41-45.

MacFarlane, R.B. and E.C. Norton. 1999. Nutritional dynamics during embryonic development in the viviparous genus *Sebastes* their application to the assessment of reproductive success. Fishery Bulletin, U.S. 97:273-281.

MacFarlane, R.B. and M.J. Bowers. 1995. Matrotrophic viviparity in the yellowtail rockfish *Sebastes flavidus*. J. exp. Biol. 198:1197-1206.

MacFarlane, R.B., E.C. Norton, and M.J. Bowers. 1993. Lipid dynamics in relation to the annual reproductive cycle in yellowtail rockfish (*Sebastes flavidus*). Canadian Journal of Fisheries and Aquatic Sciences 50:391-401.

CURRICULUM VITAE

NAME: MICHAEL S. MOHR

PRESENT POSITION: Mathematical Statistician and Team Leader, Salmon Population Analysis

EDUCATION: Graduate study, Biostatistics, University of California, Berkeley, California; M.S., Fisheries, Humboldt State University, Arcata, California, 1986; B.A., Mathematics, Humboldt State University, 1983; B.S., Fisheries, Humboldt State University, 1980.

PAST EXPERIENCE:

1996-present	Mathematical Statistician National Marine Fisheries Service Southwest Fisheries Science Center Santa Cruz, California
1994-1995	Statistical Consultant California Department of Fish and Game Ofc. of Oil Spill Prevention and Response Sacramento, California
1994	Visiting Assistant Professor Humboldt State University Departments of Mathematics and Fisheries Arcata, California

RESEARCH INTERESTS: Estimator development, population dynamics, stock assessment, fishery management under uncertainty.

HONORS AND AWARDS: Outstanding Performance Award, NFMS, 2002. Bronze Medal, DOC, 2002. Employee of the Year, NMFS, 2001. Special Service Award, NMFS, 2001. Special Act, NMFS, 2001. Outstanding Performance Award, NMFS, 1999. Special Act, NMFS, 1999. Special Act, NMFS, 1999. High Level of Performance, NMFS, 1997.

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: Fishery Management Plan Amendment Group, Central Valley Chinook, Pacific Fishery Management Council, 2002-present; Salmon Technical Team, Pacific Fishery Management Council, 1997-present; Klamath River Technical Advisory Team, Klamath Fishery Management Council, 1997-present; Coho Salmon Biological Review Team, NMFS, 1996-1997; Mass Mark Working Group, NMFS,1996-1997.

SELECTED PUBLICATIONS:

Lindley, Steven, T., and Michael S. Mohr. 2003. Modeling the effect of striped bass (*Morone saxatilis*) on the population viability of Sacramento River winter-run chinook salmon (*Oncorhynchus twhawytscha*). Fishery Bulletin 101:321-331.

Grover, Allen M., Michael S. Mohr, and Melodie L. Palmer-Zwahlen. 2002. Hook-and-release mortality of chinook salmon from drift mooching with circle hooks: management implications for California's ocean sport fishery. Pages 39-56 *in* J. A. Lucy and A. L. Studholme, editors. Catch and release in marine recreational fisheries. American Fisheries Society, Symposium 30, Bethesda, Maryland.

Prager, Michael H., and Michael S. Mohr. 2001. The harvest rate model for Klamath River fall chinook salmon, with management applications and comments on model development and documentation. North American Journal of Fisheries Management 21:533-547.

Norton, E. C., R. B. MacFarlane, and M. S. Mohr. 2001. Lipid class dynamics during development in early life stages of shortbelly rockfish and their application to condition assessment. Journal of Fish Biology 58:1010-1024.

Lindley, Steven, T., Michael S. Mohr, and Michael H. Prager. 2000. Monitoring protocol for Sacramento River winter chinook salmon, *Oncorhynchus tshawytscha*: application of statistical power analysis to recovery of an endangered species. Fishery Bulletin 98:759-766.

CURRICULUM VITAE

NAME: ELIZABETH C. NORTON

PRESENT POSITION: Research Fishery Biologist, Salmon Ecology Team

EDUCATION: B.A., Aquatic Biology, University of California, Santa Barbara, 1983.

PAST EXPERIENCE:

1990-present	Research Fishery Biologist NMFS Santa Cruz and Tiburon, California
1987-1990	Biological Technician NMFS Tiburon, California
1985-1987	Educational Sales Representative , Portland, Oregon
1984	Foreign Fisheries Observer - 3 Bering Sea Tours NMFS Seattle, Washington

RESEARCH INTERESTS: Salmon feeding ecology, zooplankton ecology, fish lipids.

HONORS AND AWARDS: Chancellor's Scholar, UCSB, 1979; NOAA Performance Awards, 1993, 1994, 1995, 1996, 2000, 2001, 2002; Co-author NOAA Fisheries best scientific publication award, 2002.

SELECTED SERVICE ON COMMITTEES: Tiburon Laboratory EEO Committee, 1989-1991; Southwest Region EEO Advisory Committee, Personnel Subcommittee Chair, 2000-2002.

VOLUNTEER ACTIVITIES: National Oceans Conference, Monterey, CA 1998; Docent, California Academy of Sciences, San Francisco, CA 1992-1996; "Expanding Your Horizons Day," Skyline College, San Bruno, CA 1990, 1992; Discovery Day, Romberg Tiburon Center for Environmental Studies, SFSU, Tiburon, CA 1989-1996; UCSB Research Aide, 1983; Scripps (CALCOFI) and NMFS research cruises, 1983.

SELECTED PUBLICATIONS:

Eldridge, M. B., E. C. Norton*, B. M. Jarvis, and R. B. MacFarlane. 2002. Energetics of early development in the vivaparous yellowtail rockfish. J. of Fish Biol. 61:1122-1134.

MacFarlane, R. B., and E. C. Norton. 2002. Physiological ecology of juvenile chinook salmon (*Onchorhynchus tshawytscha*) at the southern end of their distribution, the San Francisco Estuary and Gulf of the Farallones, California. Fish. Bull., U.S. 100:244-257.

Norton, E. C., R. B. MacFarlane, and M. S. Mohr. 2001. Lipid class dynamics during development in early life stages of shortbelly rockfish (*Sebastes jordani*) and their application to condition assessment. J. Fish Biol. 58, 1010-1024.

Norton, E. C., and R. B. MacFarlane. 1999. Lipid class composition of the viviparous yellowtail rockfish (*Sebastes flavidus*) over the reproductive cycle. J. Fish Biol. 54:1287-1299.

MacFarlane, R. B., and E. C. Norton. 1999. Nutritional dynamics during embryonic development in the viviparous genus *Sebastes* and their application to the assessment of reproductive success. Fish. Bull., U.S. 97:273-281.

MacFarlane, R. B., and E. C. Norton. 1996. Lipid and protein changes during embryo development in the viviparous genus *Sebastes*: Application to the assessment of reproductive success. *In* Don MacKinlay and Maxwell Eldridge (eds.), The fish egg: Its biology and culture, p. 95-102. International Congress on the Biology of Fishes, American Fisheries Society, Physiology Section, San Francisco State University, July 14-18, 1996.

Norton, E. C., and R. B. MacFarlane. 1995. Nutritional dynamics of reproduction in viviparous yellowtail rockfish (*Sebastes flavidus*). Fish. Bull., U.S. 93:299-307.

CURRICULUM VITAE

NAME: ROBERT S. SCHICK

PRESENT POSITION: Ecologist, Salmon Population Analysis Team

EDUCATION: M.E.M., Resource Ecology, Duke University, 2002; B.S., Zoology, University of Washington, 1997.

PAST EXPERIENCE:

2002-present	Ecologist NOAA Fisheries, Southwest Fisheries Science Center Santa Cruz, California	
2000-2002	Assistant Scientist/GIS New England Aquarium/Edgerton Research Lab Boston, Massachusetts	

RESEARCH INTERESTS: Spatial dynamics of species in relation to environmental parameters. Quantifying empirical relationships between marine species and measurable oceanographic parameters. Application of GIS & Remote Sensing to Ecological research. Connectivity in threatened populations. Numerical Ecology. Landscape Ecology.

HONORS AND AWARDS: Merit Scholarship, Nicholas School of the Environment, Duke University, 1998; Environmental Internship Fund Fellow, Duke University, Summer 1999; Dean's list, University of Washington.

SELECTED PUBLICATIONS:

Schick, R.S. 2002. Spatial Correlation between Bluefin Tuna and Sea Surface Temperature Fronts. In *Marine Geography*, J. Breman (ed.), ESRI Press Redlands, CA.

Schick, R.S. 2002. Using GIS to Track Right Whales and Bluefin Tuna in the Atlantic Ocean. In *Undersea with GIS*, D.J. Wright (ed.), ESRI Press Redlands, CA.

Schick, R.S. 2001. Tuna distribution in relation to physical features in the Gulf of Maine. In *Conservation Geography: Case Studies in GIS, Computer Mapping, and Activism*, C. Convis (ed.), ESRI Press Redlands, CA.

Schick, R.S. and D.L. Urban. 2000. Spatial components of bowhead whale (*Balaena mysticetus*) distribution in the Alaskan Beaufort Sea. Can. J. Fish. Aq. Sci. 57: 2193-2200.

CURRICULUM VITAE

NAME: MELISSA L. SNOVER

PRESENT POSITION: NRC Postdoctoral Research Associate, Pacific Fisheries Environmental Laboratory

EDUCATION: B.A., Biology & Mathematics, Potsdam College, 1986; M.S., Environmental Biology, Hood College, 1994; Ph.D., Ecology, Duke University Marine Lab, 2002

PAST EXPERIENCE:

	1997 - 2002	Research Assistant, Southeast Fisheries Science Center, Beaufort Lab
	1995 - 1997	Laboratory Supervisor, Hood College
	1994 - 1995	Laboratory Coordinator, University of Maryland – College Park
	1992 - 1994	Graduate Assistant, Hood College
	1990 - 1992	Environmental Inspector, Maryland Department of the Environment
	1988 - 1990	Laboratory Technician, Diagnostic Division, Biowhittaker, Inc.
	1986 - 1988	Research Assistant, Mailman Research Center, McLean Hospital

RESEARCH INTERESTS: Population dynamics, life history, stock assessment

HONORS AND AWARDS: New York State Regents Scholarship, 1982-1986; Pi Mu Epsilon, 1983-1986; National Dean's List, 1994; Archie Carr Best Student Presentation Award, First Runner-Up, Best Biology Poster, 1999; Archie Carr Best Student Presentation Award, First Runner-Up, Best Biology Paper, 2000; National Research Council Postdoctoral Research Associate, 2002-2003

SELECTED PUBLICATIONS:

Snover, M.L., G.M. Watters and M. Mangel. Submitted. The relationship between smolt length and age at maturity in Coho salmon (*Oncorhynchus kisutch*). *Journal of Fish Biology*.

Snover, M.L., G.M. Watters and M. Mangel. In prep. Status-dependent conditional strategies for age at maturity and reproductive tactics in coho salmon (*Oncorhynchus kisutch*). *American Naturalist*.

Snover, M.L. and A.A. Hohn. Submitted. Validation and interpretation of annual skeletal marks in loggerhead (*Caretta caretta*) and Kemp's ridley (*Lepidochelys kempi*) sea turtles. *Fishery Bulletin, U.S.*

Heppell, S.S., M.L Snover, and L.B. Crowder. 2002. Sea turtle population ecology. *In* P.Lutz and J. Wyneken, Eds., The biology of sea turtles, Volume II. CRC Press, Boca Raton, FL, USA. 275-306.

National Marine Fisheries Service Southeast Fisheries Science Center. 2001. Stock assessments of loggerhead and leatherback sea turtles and an assessment of the impact of the pelagic longline fishery on the loggerhead and leatherback sea turtles of the Western North Atlantic. U.S. Department of Commerce NOAA Technical Memorandum NMFS-SEFSC-455. 343 pp.

Snover, M.L. and J.A. Commito. 1998. The fractal geometry of *Mytilus edulis* L. spatial distribution in a soft-bottom system. *Journal of Experimental Marine Biology and Ecology*. 223: 53-64.

CURRICULUM VITAE

NAME: SUSAN M. SOGARD

PRESENT POSITION: Ecology Branch Chief

EDUCATION: Ph.D. in ecology, October 1990, Rutgers University, New Brunswick, New Jersey; M.S. in marine biology, July 1982, University of Miami, Miami, Florida; B.S. (cum laude) in zoology and psychology, May 1977.

PAST EXPERIENCE:

2001-present	Supervisory Research Fishery Biologist NMFS/NOAA/SWFSC Santa Cruz, CA	
1993-2001	Oceanographer NMFS/NOAA/AFSC Newport, OR	
1984-1987	Research Biologist National Audubon Society Tavernier, FL	

RESEARCH INTERESTS: Behavioral and population ecology of marine organisms, population dynamics and recruitment variability of early life history stages, costs of growth in juvenile fishes, life history strategies.

HONORS AND AWARDS: NOAA Special Service Award, 1999, 2000; Stoye Award, best student paper, ASIH meeting, 1990; J. Frances Allen Scholarship, American Fisheries Society, 1990.

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: Science Advisory Group of the Interagency Ecological Program on San Francisco Bay fisheries research (1999-2002); Higher Trophic Level Initiative, Florida Bay Research Program (1997); National Undersea Research Program Panel (1996); National Sea Grant Fisheries Panel (1993); EPA Global Climate Change Program (1992).

SELECTED PUBLICATIONS:

Sogard, S.M. and B.L. Olla. (in press). Contrasts in the capacity for compensatory growth and underlying mechanisms in two pelagic marine fishes. Mar. Ecol. Prog. Ser.

Sogard, S.M. and B.L. Olla. 2001. Growth and behavioral responses to elevated temperatures by juvenile sablefish (*Anoplopoma fimbria*) and the interactive role of food availability. Mar. Ecol. Prog. Ser. 217: 121-134.

Sogard, S.M., K.W. Able and S.M. Hagan. 2001. Long-term assessment of settlement and growth of juvenile winter flounder (*Pseudopleuronectes americanus*) in New Jersey estuaries. J. Sea Res. 45:189-204.

Sogard, S.M. and B.L. Olla. 2000. Effects of group membership and size distribution within a group on growth rates of juvenile sablefish *Anoplopoma fimbria*. Env. Biol. Fishes 59:199-209.

Sogard, S.M. and B.L. Olla. 2000. Endurance of simulated winter conditions by age-0 walleye pollock (*Theragra chalcogramma*): effects of body size, water temperature and energy stores. J. Fish Biol. 56:1-21.

Matheson, R.E. Jr., D.A. Camp, S.M. Sogard, and K.A. Bjorgo. 1999. Changes in seagrass-associated fish and crustacean communities on Florida Bay mud banks: the effects of recent ecosystem changes? Estuaries 22:534-551.

Sogard, S.M. and B.L. Olla. 1998. Contrasting behavioral responses to cold temperatures by two marine fish species during their pelagic juvenile interval. Env. Biol. Fish. 53:405-412.

Sogard, S.M. and B.L. Olla. 1998. Behavior of juvenile sablefish, *Anoplopoma fimbria* (Pallas), in a thermal gradient: Balancing food and temperature requirements. J. Exp. Mar. Biol. Ecol. 222:43-58.

CURRICULUM VITAE

NAME: BRIAN C. SPENCE

PRESENT POSITION: Research Fishery Biologist, Salmon Population Analysis Team

EDUCATION: Ph.D., Fisheries Science, Oregon State University, 1995; M.S., Natural Resources (Fishery Science), Cornell University, 1989; B.S., Wildlife and Fisheries Biology, University of California, Davis, 1983.

PAST EXPERIENCE:

2000-present	Research Fishery Biologist National Marine Fisheries Service Santa Cruz, California
1998-2000	Visiting Faculty, Environmental Studies The Evergreen State College, Olympia, Washington
1996-1997	Consultant, Aquatic Ecologist Umpqua Land Exchange Project Corvallis, Oregon
1995-1996	Project Scientist, Fisheries ManTech Environmental Research Services Corporation Corvallis, Oregon

RESEARCH INTERESTS: Life-history variation in Pacific salmonids; salmonid habitat relationships; effects of human perturbations on aquatic ecosystems; conservation biology of resident and anadromous fishes.

PROFESSIONAL AFFILIATIONS: American Fisheries Society

SERVICE ON SCIENTIFIC COMMITTEES: Current member of Technical Recovery Team for listed salmonids in the North Central California Coast Domain.

PUBLICATIONS:

Spence, B. C., and E. P. Bjorkstedt. In press. Central California Coast coho salmon. Pp. C47-61 *in* Updated status of listed ESUs of West Coast salmon and steelhead. West Coast Salmon Biological Review Team, NOAA Fisheries.

Spence, B. C., T. C. Wainwright, and E. P. Bjorkstedt. In press. Southern Oregon/Northern California Coasts. Pp C25-46 *in* Updated status of listed ESUs of West Coast salmon and steelhead. West Coast Salmon Biological Review Team, NOAA Fisheries.

Spence, B. C., T. H. Williams, E. P. Bjorkstedt, and P. B. Adams. 2001. Status review update for coho salmon (*Oncorhynchus kisutch*) from the Central California Coast and the California portion of the Southern Oregon/Northern California Coasts Evolutionarily Significant Units. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA.

Hobbs, S. H., R. L. Beschta, E. D. Clark, W. Dennison, J. Gabriel, S. Garman, R. Gill, S. Gregory, R. Jones, W. McComb, A. McKee, K. Pollett, W. Ripple, J. Sessions, B. C. Spence, D. Vesely, and D. Wagner. 1998. Pilot study report: Umpqua Land Exchange Project. World Forestry Center, Portland, OR. 170 p. + appendices.

Spence, B. C., G. A. Lomnicky, R. M. Hughes, and R. P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corporation, Corvallis, OR. 356 p.

Spence, B. C. 1995. Geographic variation in timing of fry emergence and smolt migration in coho salmon (*Oncorhynchus kisutch*). Ph.D. thesis, Oregon State University, Corvallis, OR. 201 p.

Gucinski, H., R. T. Lackey, and B. C. Spence. 1991. Global climate change: Policy implications for fisheries. Fisheries 15(6):33−38.

CURRICULUM VITAE

NAME: ERICK A. STURM

PRESENT POSITION: Research Fishery Biologist

EDUCATION: MA, Biology, California State University, Fullerton, 1997; BS, Biological Sciences, University of Southern California, 1991.

PAST EXPERIENCE:	2002 - present	Research Fishery Biologist NMFS, Southwest Fisheries Science Center Santa Cruz, California
	1999 - 2002	Research Fishery Biologist NMFS, Alaska Fisheries Science Center Newport, Oregon
	1997 - 1999	Biological Technician Kindred Communications, Inc. Hatfield Marine Science Center Newport, Oregon

RESEARCH INTERESTS: Diet and digestive abilities of marine herbivorous fishes, biogeography of fishes and how this changes with warm water and El Niño events, fish nutrition in captive situations, design of aquarium systems for long term holding of fishes, and improving husbandry techniques for fishes kept in experimental research facilities.

HONORS AND AWARDS: Merit Award, F/AKC, NMFS, 1999; Outstanding Service to the Department of Biological Science, California State University, Fullerton, 1997, 1996, 1995, 1994; Outstanding Teaching Award, California State University, Fullerton, 1997.

SELECTED PUBLICATIONS:

Ryer, C.H., M.L. Ottmar, and E.A. Sturm. In press. Behavioral impairment after escape from trawl codends may not be limited to fragile species. Canadian Journal of Fisheries and Aquatic Sciences.

Stoner, A.W. and E.A. Sturm. In review. Temperature and hunger mediate sablefish (*Anoplopoma fimbria*) feeding motivation: implications for stock assessment. Canadian Journal of Fisheries and Aquatic Sciences.

Sturm, E.A. and M.H. Horn. 2001. Increase in occurrence and abundance of zebraperch *(Hermosilla azurea)* in the Southern California Bight in recent decades. Bulletin of the Southern California Academy of Science.

Sturm, E.A. and M.H. Horn. 1998. Food habits, gut morphology and pH, and assimilation efficiency of the Zebraperch (*Hermosilla azurea*), an herbivorous kyphosid fish of temperate marine waters. Marine Biology, 132:515-522.

Sturm, E.A. 1997. Food habits, gut morphology and pH, and assimilation efficiency of the Zebraperch (*Hermosilla azurea*, Jenkins and Evermann), an herbivorous kyphosid fish of temperate marine waters. Master of Arts Thesis. California State University, Fullerton. 37 p.

Sturm, E.A. and M.H. Horn. 1996. Diet and digestive efficiency of zebraperch, *Hermosilla azurea,* an herbivorous fish of southern California marine waters. pp. 41-44. In: Gutshop '96: Feeding Ecology and Nutrition in Fish Symposium Proceedings. International Congress of the Biology of Fishes. San Francisco State University. (Non peer reviewed publication.)

CURRICULUM VITAE

NAME: CYNTHIA J. THOMSON

PRESENT POSITION: Economics Team Leader, Fisheries Branch

EDUCATION: M.A., University of California, San Diego, 1977; B.A., University of California, San Diego, 1972.

PAST EXPERIENCE:

1996-present	Economist NMFS/SWFSC Santa Cruz, California
1978-1996	Economist NMFS/SWFSC La Jolla, California
1975-1977	Teaching Assistant, Department of Economics University of California, San Diego La Jolla, California
1974	Research Assistant - Sea Grant Project

RESEARCH INTERESTS: Fishery management, non-market valuation, salmon habitat restoration cost estimation, design of fishery economic surveys, economics of marine protected areas.

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: Pacific Fishery Management Council, Scientific and Statistical Committee, 1991-present (vice chair 1998-1999, chair 2000-2001); Chair, SSC Marine Reserve Subcommittee, 2001-present; RecFIN Committee, 1996-present; State of California Squid Research Scientific Committee, 1999-2001; NOAA Superfund Litigation Team, 1993-1996; Pacific Fishery Management Council, Coastal Pelagics Plan Development Team, 1991-1994; Pacific Fishery Management Council, Anchovy Plan Development Team, 1989-1991.

SELECTED PUBLICATIONS:

Cai. D. and C. Thomson. In prep. A random utility model of the Pacific coast marine recreational fishery: behavioral and welfare implications of fishery regulations.

Thomson, C.J. In press. Conclusions and Recommendations. In: Allen, S. et al. (eds.) Proceedings of the Salmon Habitat Restoration Cost Workshop. Pacific States Marine Fisheries Commission, Portland, OR.

Thomson, C.J. 2001. The human ecosystem. In: Leet, W. et al. (eds.). *California's Living Marine Resources: A Status Report.* California Department of Fish and Game.

Thomson, C.J. et al. 2000. *Overcapitalization in the West Coast Groundfish Fishery: Background, Issues and Solutions*. Prepared for the Pacific Fishery Management Council by the Scientific and Statistical Committee, Economics Subcommittee. 116 p.

Thomson, C.J. 1999. Economic and implications of no-take reserves: an application to *sebastes* rockfish in California. *Calif. Coop. Oceanic Fish. Invest. Rep*. 40:107-117.

Thomson, C. 1998. Evaluating marine harvest refugia: an economic perspective. In: Yoklavich, Mary (ed.). *Marine Harvest Refugia for West Coast Rockfish: A Workshop*. U.S. Dep. Commer., NOAA Tech Memo, NOAA-TM-NMFS-SWFSC-255.

Thomson, C. 1997. Analysis of agency costs attributable to the Recovery Plan for Sacramento River winter-run chinook salmon. U.S. Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-249.

Kling, C.L. and C.J. Thomson. 1996. The implications of model specification for welfare estimation in nested logit models. *American Journal of Agricultural Economics.* 78:103-114.

CURRICULUM VITAE

NAME: DAVID TOMBERLIN

PRESENT POSITION: Economist, Fisheries Branch

EDUCATION: Ph.D., Forest Economics, University of Wisconsin - Madison, 1999; M.S., Agricultural and Resource Economics, North Carolina State University, 1993; B.A., English and Creative Writing, Princeton University, 1988.

PAST EXPERIENCE:

1999-present	Economist NMFS/ SWFSC Santa Cruz, California
1993-1999	Research Assistant Department of Forestry, University of Wisconsin
1998	Economics Consultant Food and Agriculture Organization, Rome, Italy
1992-1993	Research Assistant North Carolina State University, Raleigh, North Carolina
1988-1990	Lecturer Universitas Bung Hatta, Padang, Indonesia

RESEARCH INTERESTS: Resource management under uncertainty, real options analysis in public policy, commercial fishing fleet dynamics, fish/forestry interactions, operations research

HONORS AND AWARDS: McGovern Scholar (1997, 1998); USDA National Research Initiative grantee (1994, 1998, 2003); Southeast Asian Studies Center Fellow, 1995; Magna Cum Laude, Phi Beta Kappa, Croll Prize, 1988

SELECTED PUBLICATIONS:

Tomberlin, D. The Allocation Problem in Habitat Restoration. In Proceedings of the Habitat Restoration Cost workshop, Gladstone, OR. Forthcoming.

Buongiorno, J., S. Zhu, D. Zhang, J. Turner, and D. Tomberlin. The Global Forest Products Model: Structure, Estimation, and Applications. Academic Press. 2003.

Tomberlin, D. Modeling California Salmon Fleet Dynamics. In Proceedings of the North American Association of Fisheries Economists meeting, April 2-4. 2002.

Tomberlin, D., and J. Buongiorno. Timber Plantations, Timber Supply, and Forest Conservation. In Mati Palo, ed., World Forests, Markets, and Policies. Kluwer Academic Publishers. 2002.

Tomberlin, D. Real Options Analysis of Entry and Exit in Fisheries. Presented to the NMFS economists' national meeting, La Jolla, February 2000.

Tomberlin, D., J. Buongiorno, and D. Brooks. Trade, Forestry, and the Environment: Issues and Methods. Journal of Forest Economics 4(3):177-206. Fall 1998.

Tomberlin, D., J. Buongiorno, and S. Zhu. ASIAPAC: A Model of Consumption, Production, and Trade in the Asia-Pacific Forest Sector. FAO Forest Sector Background Paper. 1998.

CURRICULUM VITAE

NAME: GEORGE M. WATTERS

PRESENT POSITION: Supervisory Research Fishery Biologist, Pacific Fisheries Environmental Laboratory

EDUCATION: B.S., Fisheries, Humboldt State University, 1989; M.S., Fisheries, University of Washington, 1991; Ph.D., Biological Oceanography, University of California, San Diego, Scripps Institution of Oceanography, 1997

PAST EXPERIENCE:	1997 - 2001	Senior Scientist, Inter-American Tropical Tuna Commission
	1991 - 1997	Research Fishery Biologist, Southwest Fisheries Science Center, Antarctic Ecosystem Research Group

RESEARCH INTERESTS: Stock assessment, population dynamics, fisheries oceanography, ecosystem modeling

HONORS AND AWARDS: U.C. Regents Fellowship, University of California, San Diego, 1991-1997; Mason H. Keeler Fellowship, University of Washington, 1989-1991; Presidential Scholar, Humboldt State University, 1985-1989

SELECTED PUBLICATIONS:

Watters, G.M., Olson, R.J., Francis, R.C., Fiedler, P.C., Polovina, J.J., Reilly, S.B., Aydin, K.Y., Boggs, C.H., Essington, T.E., Walters, C.J., and Kitchell, J.F. In press. Physical forcing and the dynamics of the pelagic ecosystem in the eastern tropical Pacific: simulations with ENSO-scale and global-warming climate drivers. *Canadian Journal of Fisheries and Aquatic Sciences*.

Maunder, M.N., Watters, G.M., and Harley, S.J. In press. A-SCALA: an age-structured statistical catch-at-length analysis for assessing tuna stocks in the eastern Pacific Ocean. *Inter-American Tropical Tuna Commission, Bulletin.*

Maunder, M.N. and Watters, G.M. 2003. A general framework for integrating environmental time series into stock assessment models: model description, simulation testing, and example. *Fishery Bulletin, U.S.* 101: 89-99.

Olson, R.J. and Watters, G.M. 2003. A model of the pelagic ecosystem in the eastern tropical Pacific Ocean. *Inter-American Tropical Tuna Commission, Bulletin*. 22(3): 133-217.

Watters, G. and Maunder, M. 2002. Status of bigeye tuna in the eastern Pacific Ocean. *Inter-American Tropical Tuna Commission, Stock Assessment Report.* 2: 147-246.

Maunder, M. and Watters, G. 2002. Status of yellowfin tuna in the eastern Pacific Ocean. *Inter-American Tropical Tuna Commission, Stock Assessment Report.* 2: 5-90.

Maunder, M. and Watters, G. 2002. Status of skipjack tuna in the eastern Pacific Ocean. *Inter-American Tropical Tuna Commission, Stock Assessment Report.* 2: 91-146.

Watters, G. and Maunder, M. 2001. Status of bigeye tuna in the eastern Pacific Ocean. *Inter-American Tropical Tuna Commission, Stock Assessment Report.* 1: 109-210.

Maunder, M. and Watters, G. 2001. Status of yellowfin tuna in the eastern Pacific Ocean. *Inter-American Tropical Tuna Commission, Stock Assessment Report.* 1: 5-86.

Watters, G. and Deriso, R. 2000. Catch per unit of effort of bigeye tuna: a new analysis with regression trees and simulated annealing. *Inter-American Tropical Tuna Commission, Bulletin.* 21: 527-571.

Watters, G. 1998. Prevalences of parasitized and hyperparasitized crabs near South Georgia. *Marine Ecology Progress Series.* 170: 215-229.

Watters, G. and Hobday, A.J. 1998. A new method for estimating the morphometric size at maturity of crabs. *Canadian Journal of Fisheries and Aquatic Sciences.* 55: 704-714.

CURRICULUM VITAE

NAME: THOMAS H. WILLIAMS

PRESENT POSITION: Research Fishery Biologist, Salmon Population Analysis Team

EDUCATION: Ph.D. candidate, Fisheries Science, Oregon State University; M.S., Fish and Wildlife Management, Montana State University, Bozeman, 1990; B.S., Fisheries, Humboldt State University, 1985.

PAST EXPERIENCE:

	1998 - present	Research Fishery Biologist, NMFS Santa Cruz, California
	1992 - 1998	Graduate Research/Teaching Assistant Department of Fisheries and Wildlife Oregon State University, Corvallis, Oregon
	1991 - 1992	Research Assistant, Oregon Cooperative Wildlife Research Unit Staff member - Northern Spotted Owl Recovery Team Oregon State University, Corvallis, Oregon

RESEARCH INTERESTS: Ecology of Pacific salmonids and relations among marine, freshwater, and terrestrial communities; conservation biology and conservation genetics related to conservation of Pacific salmon and trout.

PROFESSIONAL AFFILIATIONS: American Fisheries Society, Ecological Society of America, Gilbert Ichthyological Society, The Wildlife Society

SELECTED SERVICE ON SCIENTIFIC COMMITTEES: Member of technical panel for NMFS workshop on Assessing Extinction Risk for West Coast Salmonids, Seattle, 1996; Biological Review Team, Coastal Cutthroat Trout 1998; Biological Review Team, Klamath Mountains Province Steelhead 2001; Chairman, Technical Recovery Team, Southern Oregon/Northern California Recovery Domain, present.

SELECTED PUBLICATIONS:

Williams, T. H., and G. H. Reeves. 2003. Ecological diversity and extinction risk of Pacific salmon and trout. Pages 107-115 *in* A.D. MacCall and T. C. Wainwright, editors. Assessing extinction risk for West Coast salmon. U.S. Dept. of Commer., NOAA Tech. Memo. NMFS-NWFSC-56, 198 p.

Spence, B. C., T. H. Williams, E. P. Bjorkstedt, and P. B. Adams. 2001. Status review update for coho salmon (*Oncorhynchus kisutch*) from the Central California Coast and the California portion of the Southern Oregon/Northern California Coasts Evolutionarily Significant Units. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA.

Williams, T. H., and G. H. Reeves. 2001. Identification and conservation considerations of hybrids between coastal cutthroat trout and steelhead trout. Pages 259-260 *in* M. K. Brewin, A. J. Paul, and M. Monita, editors. Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Currens, K. P., F. W. Allendorf,, D. Bayles, D. L. Bottom, C. A. Frissell, D. Hankin, J. A. Lichatowich, P. C. Trotter, and T. H. Williams. 1998. Conservation of Pacific Salmon: response to Wainwright and Waples. Conservation Biology 12(5):1148-1149.

Williams, T. H., K. P. Currens, N. E. Ward III, and G. H. Reeves. 1997. Genetic population structure of coastal cutthroat trout. Pages 16-17 *in* J. D. Hall, P. A. Bisson, and R. G. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis, OR.

Allendorf, F. W., D. Bayles, D. L. Bottom, K. P. Currens, C. A. Frissell, D. Hankin, J. A. Lichatowich, W. Nehlsen, P. C. Trotter, and T. H. Williams. 1997. Prioritizing Pacific salmon stocks for conservation. Conservation Biology 11:140-152.

Williams, T. H., and R. G. White. 1990. Evaluation of pressure-sensitive radio transmitters used for monitoring depth selection by trout in lotic systems. American Fisheries Society Symposium 7:390-394.

APPENDIX B

SALMON-RELATED PUBLICATIONS

SANTA CRUZ LABORATORY
PACIFIC FISHERIES ENVIRONMENTAL LABORATORY

CURRENT MANUSCRIPTS

Adams, P. B., **W. M. Samiere**, and **C. J. Ryan**.
In prep. Diet and prey switching of a marine predator, chinook salmon (*Oncorhynchus tshawytscha*) and their management implications.

Agrawal, A., **R. G. Szerlong**, and **E. Bjorkstedt**.
In prep. An evaluation of interpolation methods for increasing DEM resolution with application to estimating fine-scale stream gradient.

Alonzo, J. J., and **R. B. MacFarlane**.
In prep. Smoltification in chinook salmon (*Oncorhynchus tshawytscha*) from California's central valley.

Bessey, C., N. R. Liley, R. H. Devlin, and C. A. Biagi.
In prep. Reproductive performance of growth-enhanced transgenic coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences.

Bjorkstedt, E. P.
In prep. Competition in common habitats: implications for the metapopulation dynamics of stage-structured species. American Naturalist.

Bjorkstedt, E. P.
In prep. Estimating population size in small populations using stratified mark-recapture techniques. North American Journal of Fisheries Management.

Boughton, D. A.
In prep. A practical method for estimating uncertainty about the absence of species.

Boughton, D. A., and **H. Fish**.
In prep. Current distribution of steelhead (*Oncorhynchus mykiss*) in coastal streams of southern California.

Goldwasser, L., **M. S. Mohr**, A. M. Grover, and M. L. Palmer-Zwahlen.
In prep. The Klamath ocean harvest model: supporting databases and analyses.

Hankin, D. G., and **M. S. Mohr**.
In prep. Two-phase survey designs for estimation of fish abundance in small streams.

Hinke, J. T., **G. M. Watters**, G. W. Boehlert, and P. Zedonis.
In prep. Comparison of autumn ocean habitat use by Chinook salmon in coastal waters of Oregon and California. Marine Ecology Progress Series.

Johnson, R. C., and **R. B. MacFarlane**.
In prep. Estuary use and growth history of juvenile Chinook salmon from the California Central Valley juvenile in the San Francisco Bay Estuary.

Johnson, R. C., **C. B. Grimes**, and **C. F. Royer**.
In prep. Discrimination of hatchery and wild chinook salmon (*Onchorynchus tshawysha*) in the California Central Valley using otolith microstructure.

MacFarlane, R. B., **S. Ralston**, **C. Royer**, and **E. C. Norton**.
In prep. Effect of El Nino on growth of juvenile chinook salmon in the coastal waters of California.

Newman, K. B., and **S. T. Lindley**.
In prep. Modeling the population dynamics of winter-run chinook salmon using adult escapement and juvenile production estimates.

Norton, E. C., and **R. B. MacFarlane**.
In prep. Feeding habits of juvenile salmon (*Onchorhynchus tshawytscha*) in the San Francisco Estuary.

O'Hanley, J., and **D. Tomberlin**.
In prep. Optimizing resource allocation for the protection and restoration of salmon habitat.

Snover, M. L., **G. M. Watters**, and M. Mangel.
In prep. Status-dependent conditional strategies for age at maturity and reproductive tactics in coho salmon (*Onchorhynchus kisutch*). American Naturalist.

Snover, M. L., **G. M. Watters**, and M. Mangel.
Submitted. The relationship between smolt length and age at maturity in Coho salmon (*Oncorhynchus kisutch*). Journal of Fish Biology.

Thomson, C.
In review. Conclusions and recommendations. In: Stan Allen, Robin Carlson, and Cynthia Thomson (eds.), Proceedings of the Salmon Habitat Restoration Cost Workshop.

LIST OF PUBLICATIONS BY YEAR

PUBLICATIONS – IN PRESS

Bjorkstedt, E. P., and **B. Spence**.
In press. California coastal chinook. In: Updated status of listed ESUs of West Coast salmon and steelhead, p. A93-A102. National Marine Fisheries Service, West Coast Salmon Biological Review Team.

Boughton, D. A.
In press. South-Central California Coast steelhead. In: Updated status of listed ESUs of West Coast salmon and steelhead, p. B77-B82. National Marine Fisheries Service, West Coast Salmon Biological Review Team.

Boughton, D. A.
In press. Southern California steelhead. In: Updated status of listed ESUs of West Coast salmon and steelhead, p. B83-B89. National Marine Fisheries Service, West Coast Salmon Biological Review Team.

Boughton, D. A., and **E. P. Bjorkstedt**.
In press. Central California Coast steelhead. In: Updated status of listed ESUs of West Coast salmon and steelhead, p. B70-B76. National Marine Fisheries Service, West Coast Salmon Biological Review Team.

Boughton, D. A., and **E. P. Bjorkstedt**.
In press. Northern California steelhead. In: Updated status of listed ESUs of West Coast salmon and steelhead, p. B58-B69. National Marine Fisheries Service, West Coast Salmon Biological Review Team.

Lindley, S. T.
In press. California Central Valley steelhead. In: Updated status of listed ESUs of West Coast salmon and steelhead, p. B90-B99. National Marine Fisheries Service, West Coast Salmon Biological Review Team.

Lindley, S. T.
In press. Central Valley spring-run chinook. In: Updated status of listed ESUs of West Coast salmon and steelhead, p. A110-A118. National Marine Fisheries Service, West Coast Salmon Biological Review Team.

Lindley, S. T.
In press. Sacramento River winter-run chinook. In: Updated status of listed ESUs of West Coast salmon and steelhead, p. A103-A109. National Marine Fisheries Service, West Coast Salmon Biological Review Team.

Spence, B., and **E. P. Bjorkstedt**.
In press. Central California coho. In: Updated status of listed ESUs of West Coast salmon and steelhead, p. C47-C61. National Marine Fisheries Service, West Coast Salmon Biological Review Team.

Spence, B., T. C. Wainwright, and **E. P. Bjorkstedt**.
In press. Southern Oregon / Northern California coasts coho. In: Updated status of listed ESUs of West Coast salmon and steelhead, p. C25-C46. National Marine Fisheries Service, West Coast Salmon Biological Review Team.

Tomberlin, D.
In press. Modeling California salmon fleet dynamics. In: Proceedings of the 2001 North American Association of Fisheries Economists meeting.

Tomberlin, D.
In press. The allocation problem in habitat restoration. In: Proceedings of the NMFS Habitat Restoration Cost workshop.

PUBLICATIONS – 2003

Klamath River Technical Advisory Team.
2003. Klamath River fall chinook age-specific escapement, 2001 run. Klamath Fishery Management Council, Yreka, California.

Klamath River Technical Advisory Team.
2003. Klamath River fall chinook age-specific escapement, 2002 run. Klamath Fishery Management Council, Yreka, California.

Klamath River Technical Advisory Team.
2003. Ocean abundance projections and prospective harvest levels for Klamath River fall chinook, 2003 season. Klamath Fishery Management Council, Yreka, California.

Lindley, S. T.
2003. Estimation of population growth and extinction parameters from noisy data. Ecological Applications 13(3):806-813.

Lindley, S. T., and **M. S. Mohr**.
2003. Modeling the effect of striped bass (*Morone saxatilis*) on the population viability of Sacramento River winter-run chinook salmon (*Oncorhynchus tshawytscha*). Fishery Bulletin 101(2):321-331.

MacCall, A. D., and T. C. Wainwright (editors).
2003. Assessing extinction risk for West Coast salmon: Proceeding of the workshop (November 13-15, 1996, Seattle, Washington). NOAA Technical Memorandum NMFS-NWFSC-56. 197 p.

Salmon Technical Team.
2003. Review of 2002 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Salmon Technical Team.
2003. Preseason report I: stock abundance analysis for 2003 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Salmon Technical Team and Staff Fishery Economics Staff Officer.
2003. Preseason report II: analysis of proposed regulatory options for 2003 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Salmon Technical Team and Council Staff.
2003. Preseason report III: analysis of council adoped management measures for 2003 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Williams, T. H., and G. H. Reeves.
2003. Ecosystem diversity and the extinction risk of Pacific salmon and trout. In: A. D. MacCall and T. C. Wainwright, Assessing extinction risk for west coast salmon: proceedings of the workshop (November 13-15, 1996, Seattle, Washington), p. 107-115. NOAA Technical Memorandum NMFS-NWFSC-56.

PUBLICATIONS – 2002

Grover, A. M., **M. S. Mohr**, and M. L. Palmer-Zwahlen.
2002. Hook-and-release mortality of chinook salmon from drift mooching with circle hooks: management implications for California's ocean sport fishery. In: J. A. Lucy and A. L. Studholme (eds.), Catch and release in marine recreational fisheries, p. 39-56. American Fisheries Society Symposium 30.

Klamath River Technical Advisory Team.
2002. Ocean abundance projections and prospective harvest levels for Klamath River fall chinook, 2002 season. Klamath Fishery Management Council, Yreka, California.

Koslow, J. A., **A. J. Hobday**, and **G. W. Boehlert**.
2002. Climate variability and marine survival of coho salmon (*Oncorhynchus kisutch*) off the coast of California, Oregon and Washington. Fisheries Oceanography. 11:65-77.

MacFarlane, R. B., and **E. C. Norton**.
2002. Physiological ecology of juvenile chinook salmon (*Onchorhynchus tshawytscha*) at the southern end of their distribution, the San Francisco Estuary and Gulf of the Farallones, California. Fishery Bulletin 100:244-257.

MacFarlane, R. B., **S. Ralston**, **C. Royer**, and **E. C. Norton**.
2002. Influences of the 1997-1998 El Nino and 1999 La Nina on juvenile chinook salmon in the Gulf of the Farallones. PICES Scientific Report 20:25-29.

Salmon Technical Team.
2002. Preseason report I: Stock abundance analysis for 2002 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Salmon Technical Team.
2002. Preseason report II: Analysis of proposed regulatory options for 2002 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Salmon Technical Team.
2002. Preseason report III: Analysis of council adopted management measures for 2002 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Salmon Technical Team.
2002. Review of 2001 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

PUBLICATIONS – 2001

Adams, P.
2001. Salmon. In: H. A. Karl, et al. (eds.), Beyond the Golden Gate: oceanography, geology, biology, and environmental issues in the Gulf of the Farallones (full-length technical version), p. 146-149. U.S. Geological Survey Circular 1198.

Cole, J., **G. W. Boehlert**, and **L. deWitt**.
2001. Forecasting coho salmon survival off the Pacific northwest. Proceeding of the North Pacific Anadromous Fisheries Committee Workshop. Tokyo, Japan.

Friedland, K. D., R. V. Walker, N. D. Davis, K. W. Myers, **G. W. Boehlert**, S. Urawa, and Y. Ueno.
2001. Open-ocean orientation and return migration routes of chum salmon based on temperature data from storage tags. Marine Ecology Progress Series. 216:235-252.

Garza, J. C., and E. G. Williamson.
2001. Detection of reduction in population size using data from microsatellite loci. Molecular Ecology 10:305-318.

Hobday, A. J., and **G. W. Boehlert**.
2001. The Role of nearshore ocean variation in spatial and temporal patterns in survival and size of coho salmon. Canadian Journal of Fisheries and Aquatic Sciences. 58:2021-2036.

Klamath River Technical Advisory Team.
2001. An in-season recreational chinook harvest predictor for the Klamath River basin. Klamath Fishery Management Council, Yreka, California.

Klamath River Technical Advisory Team.
2001. Ocean stock size projections and prospective harvest levels for Klamath River fall chinook, 2001 season. Klamath Fishery Management Council, Yreka, California.

Prager, M. H., and **M. S. Mohr**.
2001. The harvest rate model for Klamath River fall chinook salmon, with management applications and comments on model development and documentation. North American Journal of Fisheries Management 21(3):533-547.

Salmon Technical Team.
2001. Preseason report I: Stock abundance analysis for 2001 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Salmon Technical Team.
2001. Preseason report II: Analysis of proposed regulatory options for 2001 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Salmon Technical Team.
2001. Preseason report III: Analysis of council adopted management measures for 2001 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Salmon Technical Team.
2001. Queets coho stock assessment. Pacific Fishery Management Council, Portland, Oregon.

Salmon Technical Team.
2001. Review of 2000 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Spence, B. C., **T. H. Williams**, **E. P. Bjorkstedt**, and **P. B. Adams**.
2001. Status review update for coho salmon (*Oncorhynchus kisutch*) from the Central California Coast and the California portion of the Southern Oregon/Northern California Coasts Evolutionarily Significant Units. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz Laboratory, California. 111 p. (April 12, 2001 revision. Individual authors not specified in publication.)

Thomson, C. J.
2001. Human ecosystem dimension. In: W. S. Leet, et al. (eds.), California's living marine resources: a status report, p. 47-66. California Department of Fish and Game.

Williams, T. H.
2001. Coastal cutthroat trout. In: W. S. Leet, et al. (eds.), California's living marine resources: a status report, errata p. 3-5 (p. 4-6 in online version of errata). California Department of Fish and Game. [Note: Originally published version, p. 426-427 and 555, contains significant editorial errors and should be disregarded.]

Williams, T. H., and G. H. Reeves.
2001. Identification and conservation considerations of hybrids between coastal cutthroat trout and steelhead trout. In: M. K. Brewin, et al. (eds.), Bull Trout II Conference Proceedings, p. 259-260. Trout Unlimited Canada, Calgary, Alberta.

Yurok Tribal Fisheries Program.
2001. An assessment of pinniped predation upon fall-run chinook salmon in the Klamath River estuary, CA, 1998. Yurok Tribal Fisheries Program, Klamath, California.

Yurok Tribal Fisheries Program.
2001. An assessment of pinniped predation upon fall-run chinook salmon in the Klamath River estuary, CA, 1999. Yurok Tribal Fisheries Program, Klamath, California.

PUBLICATIONS – 2000

Bjorkstedt, E. P.

2000. DARR (Darroch Analysis with Rank-Reduction): a method for analysis of stratified mark-recapture data from small populations, with application to estimating abundance of smolts from outmigrant trap data. NMFS SWFSC Administrative Reports SC-00-02.

Bjorkstedt, E. P.

2000. Stock-recruitment relationships for life cycles that exhibit concurrent density dependence. Canadian Journal of Fisheries and Aquatic Sciences 57:459-467.

Botkin, D. B., D. L. Peterson, and J. M. Calhoun (technical eds.).

2000. The scientific basis for validation monitoring of salmon for conservation and restoration plans (**F.B. Schwing** contributing author). Olympic Natural Resources Center Technical Report. University of Washington, Olympic Natural Resources Center, Forks, WA. 82 p.

Brodeur, R. D., **G. W. Boehlert**, E. Casillas, **M. B. Eldridge**, J. H. Helle, W. T. Peterson, W. R. Heard, **S. T. Lindley**, and M. H. Schiewe.

2000. A coordinated research plan for estuarine and ocean research on Pacific salmon. Fisheries. 25(6):7-16.

Cole, J.

2000. Coastal sea surface temperature and coho salmon production off the northwest United States. Fisheries Oceanography. 9:1-16.

Goldwasser, L., **M. S. Mohr**, A. M. Grover, M. L. Palmer-Zwahlen, S. Barrow, and C. Melcher.

2000. The supporting databases and analyses for the revision of the Klamath ocean harvest model: a progress report. Klamath Fishery Management Council, Yreka, California.

Klamath River Technical Advisory Team.

2000. Ocean stock size projections and prospective harvest levels for Klamath River fall chinook, 2000 season. Klamath Fishery Management Council, Yreka, California.

Lindley, S. T., **M. S. Mohr**, and **M. H. Prager**.

2000. Monitoring protocol for Sacramento River winter chinook salmon, *Oncorhynchus tshawytscha*: application of statistical power analysis to recovery of an endangered species. Fishery Bulletin 98:759-766.

MacFarlane, R. B.
2000. Use of the San Francisco Estuary by juvenile chinook salmon. In: J. Cech, Jr., et al. (eds.), Fish migration and passage, p. 41-45. International Congress on the Biology of Fish, American Fisheries Society, Bethesda, MD.

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